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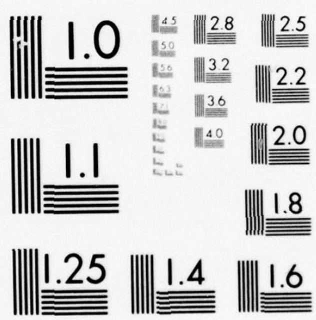
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TECHNICAL REPORT RL-77-6

REUSABILITY OF FILAMENT-WOUND COMPOSITE LAUNCH TUBES WHEN SUBJECTED TO THE EXHAUST OF ROCKETS USING ALUMINIZED PROPELLANT

Ground Equipment and Materials Directorate
US Army Missile Research, Development and Engineering Laboratory
US Army Missile Command
Redstone Arsenal, Alabama 35809

and

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21 December 1976

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U.S. ARMY MISSILE COMMAND
Redstone Arsenal, Alabama 35809

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

It is the intent of this report to initiate the search for material combinations that will permit the repeated use of filament-wound launch tubes with rockets having aluminized propellant.

Initial qualitative screening was accomplished, under contract, by the Brunswick Corporation. Further in-house evaluation was performed on tube

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ABSTRACT (Concluded)

sections containing selected material combinations resulting from the initial screening process.

The use of various material combinations as a basic tube matrix was unproductive. It seems that a liner is essential to the reuse of filament-wound launch tubes.

Several liner material combinations for filament-wound tubes are proposed for scaled live-firing tests with motors having aluminized propellant. It is also recommended that qualitative screening be continued for other liner material combinations.

CONTENTS

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I. INTRODUCTION

The use of filament-wound launch tubes has been centered in the lightweight, low cost, throw-away type weapons. These typically have been the shoulder-fired weapons. Because of the desirable strength-to-weight ratio of the filament-wound composites, they are likely candidates for the larger vehicle-mounted, multi-round rocket systems. However, the more recently developed rockets use an aluminized propellant. The exhaust produced by this propellant is very erosive or ablative to most materials. Experience with the shoulder-fired weapons has shown that some of the more common filament/resin systems will not repeatably withstand the exhaust from the larger relatively slower rockets. If the advantages of the filament-wound composites are to be realized, more suitable material combinations will have to either be found or developed. If such combinations do not materialize, then overwrapped tube liners may provide an alternate solution.

Cost is one overriding factor. To be of any practical use, the filament-wound launch tube must be competitive with its metal counterpart. If it is not competitive, then it must provide advantages that will justify a cost increase.

II. APPROACH

This investigation is planned for a two-step approach to the problem of reusability. The first step is to be a qualitative screening process involving matrix materials, complexity of tube wall construction, and liner materials. Secondly, scaled line motor firings that use aluminized propellants will be coupled with model filament-wound tube sections fabricated from selected materials.

Cost is to be a prime onsideration. The least expensive materials and tube constructions are to be used initially, with progression into the more expensive proprietary as patented resins and tube constructions. The possibilities offered by metallic liners are not to be excluded.

This reported effort involves only the qualitative screening process for materials that appear to be the most suitable, and involves only the more common winding techniques.

III. DISCUSSION

The exhaust from a rocket using aluminized propellant imposes a very severe ablative environment on the bore of a filament-wound launch tube. The observed effect is an ablating away of the resin matrix exposing the underlying filament to the exhaust environment. This not only weakens the tube wall, but prevents reuse because of the snagging of filaments during the reloading process. It also effects a diametral tolerance change that could easily affect rocket performance.

Ablation of the launch tube bore results from the interaction of heat, particle abrasion, and exhaust gas velocity. The difficulty arises in trying to assess the damage each one inflicts on the tube bore surface. There does not appear to be any inexpensive test or analytical technique to separate the interaction.

To facilitate the selection of materials, a contract was obtained with the Defense Division of Brunswick Corporation. The scope required an initial material search, a limited material assessment, and the furnishing of 12 filament-wound tube sections fabricated from materials selected by their screening process. A report of the Defense Division's efforts is included in Appendix B.

All filament-wound tube sections for screening purposes are to have a basic construction. All sections are to have an approximate inside diameter of 79 mm (3.1 in.). The wall is to contain E-glass (Type 801AB, 12 end roving) applied at 0.55 rovings per mm (14 rovings per in.) on winding angles of ±10 deg. A minimum of four layers are to be applied to an approximate thickness of 1.02 mm (0.040 in.). A deviation in the number of ends per roving is permitted, provided compensation is made in the amount of filament wound. The reason for having a basic construction is that some material screening has been done under live rocket firing conditions (Tables 1 and 2).

Of the twelve tube sections furnished by contract, five tube sections are without bore liners (Table 3) and seven tube sections are with bore liners (Table 4).

A. Screening Test Method

The selected method for screening specimens cut from the contract furnished tube sections used a fixed position, nitrogen-fed plasma gun as a heat source (Appendix A, Figure A-1). Test specimens were attached to a sliding mount which moved the specimen into and out of the flame in a pneumatically-controlled and timed cycle. The specimens were mounted at 45 deg to the flame centerline and 76 mm (3 in.) from the nozzle exit. Exposure time for each specimen was 1.5 sec. For determining heat input to the specimens, the tests were calibrated with a cold water calorimeter. Three series of tests were performed and, for purposes of identification, are called heat, heat plus grit, and high heat. The first test condition (heat) was calibrated at an input of 113.80 cal/cm^2 sec (419.6 Btu/ft^2 sec), the second (heat plus grit) was calibrated at 118.68 cal/cm^2 sec (437.6 Btu/ft^2 sec) and the third (high heat) was calibrated at 244.08 cal/cm^2 sec (900.0 Btu/ft^2 sec). A silicon carbide grit, with a fineness of 400 mesh, was used in the heat plus grit test series. The grit was injected into the gas flow within the body of the plasma gun, thereby acquiring heat and velocity.

TABLE 1. LAUNCH TUBES WITHOUT BORE LINERS USED IN LIVE ROCKET FIRINGS*

Launcher or Tube No.	Matrix Material
GEM502-5-168	Epon 828 resin NMA hardener BDMA accelerator Silicon carbide filler
GEM502-5-169	Epon 828 NMA hardener BDMA accelerator Carbon black
GEM502-5-170	Epon 828 resin NMA hardener BDMA accelerator Silicon carbide - filler Carbon black - filler
GEM502-5-171	Epon 828 resin NMA hardener BDMA accelerator Molybdenum disulfide filler
GEM502-5-172	Epon 828 resin NMA hardener BDMA accelerator Molybdenum disulfide filler Carbon black filler
GEM502-5-173	Epon 828 resin NMA hardener BDMA accelerator Molybdenum disulfide filler Silicon carbide filler Carbon black filler
FFR-1 (stepped)**	Epon 826 resin Tonox 6040 hardener
FFR-2 (straight)†	Epon 826 resin Tonox 6040 hardener

*All tube inside diameters 74.04 mm (2.915 in.) unless noted.

**Tube inside diameters: aft end - 228.6 mm (9.00 in.), forward end - 203.2 mm (7.00 in.).

†Tube inside diameter - 203.2 mm (8.00 in.).

TABLE 2. LAUNCH TUBES WITH BORE LINERS USED IN LIVE ROCKET FIRINGS*

Tube No.	Matrix Material	Liner Material
501-5-322	Epon 828 resin TETA hardener	Epon 828 resin TETA hardener Cab-o-sil filler
501-5-325	Epon 828 resin NMA hardener BDMA accelerator	Epon 828 resin TETA hardener Cab-o-sil filler
FFR-4 (straight)**	Epon 826 resin Tonox 6040 hardener	Epon 826 resin Tonox 6040 hardener Cab-o-sil filler

*All tube inside diameters 74.04 mm (2.915 in.) unless otherwise noted.

**Tube inside diameter 203.2 mm (8.00 in.).

TABLE 3. TUBE SECTIONS WITHOUT BORE LINERS, BRUNSWICK CONTRACT

Tube No.	Matrix Material
002	Epon 828 resin Ciba 906 hardener ATC-3 accelerator
003	APCO 2447 resin system
012	Dow XD-7575.02 resin Dow XD-7818 resin Epoxide 8 resin Tonox 6040 hardener
015 (baseline)	Epon 828 resin Ciba 906 hardener BDMA accelerator
019	XYLOC 235C (proprietary high temperature resin system)

Note: Tube inside diameter 79 mm (3.1 in.).

TABLE 4. TUBE SECTIONS WITH BORE LINERS, BRUNSWICK CONTRACT

Tube No.	Matrix Material	Liner Material
006	Epon 828 resin Ciba 906 hardener BDMA accelerator	Epon 828 resin EPI-cure 874 hardener Chopped graphite fiber
013	Epon 828 resin Ciba 906 hardener BDMA accelerator	Polane
014	Epon 828 resin Ciba 906 hardener BDMA accelerator	Epon 828 resin Ciba 906 hardener BDMA accelerator Cab-o-sil filler
017	Epon 828 resin Ciba 906 hardener BDMA accelerator	Dow XD-7575.02 resin Dow XD-7818 resin Epoxide 8 resin Tonox 6040 hardener
020	Epon 828 resin Ciba 906 hardener BDMA accelerator	Apco 2447 resin system Chopped graphite roving filler
021	Epon 828 resin Ciba 906 hardener BDMA accelerator	Epon 828 resin Ciba 906 hardener ATC-3 accelerator Cab-o-sil filler
022	Epon 828 resin Ciba 906 hardener BDMA accelerator	Apco 2447 resin system Cab-o-sil filler

Note: Tube inside diameter 79 mm (3.1 in.).

B. Bore Surface Temperature

The following brief thermal analysis is made to obtain an approximation of the material temperature at the surface of the tube bore. It becomes invalid if ablation of the bore surface occurs.

Diffusivity:

$$\alpha = \frac{k}{\rho C_p} , \qquad (1)$$

where

k = thermal conductivity, cal/cm sec °C (Btu ft/ft^2 sec °F)

ρ = density, g/cm^3 (lb/ft^3)

C_p = specific heat, cal/g °C (Btu/lb °F)

α = diffusivity, cm^2/sec (ft^2/sec).

Relative time factor:

$$x = \frac{\alpha \theta}{\delta^2} \quad , \tag{2}$$

where

α = diffusivity, cm^2/sec (ft^2/sec)

θ = time, sec

δ = material thickness, cm (ft)

x = relative time factor, nondimensional.

Computing surface temperature at time θ:

$$T = \frac{q \, \delta \, Z_1}{k} + T_0 \quad , \tag{3}$$

where

q = heat input, cal/cm^2 sec (Btu/ft^2 sec)

δ = material thickness, cm (ft)

k = thermal conductivity, cal/cm sec °C (Btu/ft^2 sec °F)

T_0 = initial surface temperature, °C (°F)

T = surface temperature at time θ, °C (°F)

Z_1 = function versus time factor, nondimensional.

The Z_1 function is taken from a chart [Figure 1 — function Z_1 versus time factor (4)] in a report by Jordan.[1]

These equations yield the following results for missile No. 3 (reference page 4, Appendix B) using values obtained from the plastic properties chart.[2]

Because specific values for the various composite specimens were not available, the following values were selected as representative:

Specimens without liners — epoxy resins, glass fiber filled.

$k = 10 \times 10^{-4}$ cal/cm sec °C (6.72×10^{-5} Btu ft/ft^2 sec °F)

$C_p = 0.19$ cal/g °C (Btu/lb °F)

$\rho = 1.922$ g/cm^3 (120 lb/ft^2)

$\theta = 0.008$ sec

$\delta = 0.1016$ cm (0.00333 ft)

$T_0 = 23.9$°C (75°F).

Substituting these values into Equations (1), (2), and (3) gives:

$\alpha = 2.738 \times 10^{-3}$ cm^2/sec (2.95×10^{-6} ft^2/sec)

$x = 0.002122$

$Z_1 = 0.051$

$T = 613.6$°C (1136°F).

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[1] Jordan, Jr., W. Y., An Analytical Procedure for Calculating Transient Temperature Distribution in Flat Plates Exposed to High Heat Ratios, 3 October 1957, Report No. ABMA-DS-TN-97.

[2] 1975-1976 Modern Plastics Encyclopedia, McGraw-Hill Book Company, New York, 1976.

Specimens with liners — cast resins, silica filled

$k = 20 \times 10^{-4}$ cal/cm sec °C (1.344×10^{-4} Btu ft/ft^2 sec °F)

$C_p = 0.19$ cal/g °F (Btu/lb °F)

$\rho = 1.922$ g/cm^3 (120 lb/ft^3)

$\theta = 0.008$ sec

$\delta = 0.0508$ cm (0.001667 ft)

$T_0 = 23.9$°C (75°F).

Substituting into Equations (1), (2), and (3) yields:

$\alpha = 4.336 \times 10^{-6}$ cm^2/sec (4.667×10^{-6} ft^2/sec)

$x = 0.0135$

$Z_1 = 0.13$

$T = 399.7$°C (752°F).

Note that the liner thickness is assumed to be 0.051 cm (0.020 in.) thick.

The calculated surface temperature values (T) give an additional assessment factor if they are considered along with the knowledge that resin cure temperatures can be as high as 260°C (500°F) and resin burn-out tests are accomplished at 537.8°C (1000°F) for 4 hours.

C. Observations

Data, in some form, have been collected from three different types of tests: live firings, oxyacetelyene torch, and plasma gun. Because of differences in these tests and the circumstances surrounding them, a common evaluation base could not be implemented.

Appendix B (Table I) gives characteristics of three rockets under consideration. These rockets are representative of rockets with accelerations ranging from a high to a low.

1. Live Rocket Firings

Some of the earlier rocket firings using filament-wound launchers were involved in programs with compressed time frames. Results from these firings were obtained visually. In later firings, the aft bore diameters were measured before and after the firings.

Tables 1 and 2 group launch tubes or launchers used in the earlier tests. The first six launch tubes (Table 1) had initial gel coats containing the additives applied to the winding mandrels. These gel coats were not permitted to cure prior to winding the tube. This distributed the additive carrying resin within approximately the first wound layer of the tube. These tubes were used to launch small diameter, high acceleration rockets (Table I, rocket No. 3, Appendix B). The exhaust from these rockets impinged directly onto the tube wall from the nozzle exit plane. All six tubes incurred a loss of the matrix material to an approximate depth of one layer [0.38 mm (0.015 in.)]. This left the filaments exposed and the launch tubes unsuitable for reuse.

The remaining two launchers (Table 1) were representative of those for larger rockets with intermediate accelerations (Table I, rocket No. 1, Appendix B). The exhaust from this rocket does not impinge directly on the tube bore from the nozzle exit plane [147.3 mm (5.80 in.)] nozzle exit diameter as compared to a bore diameter of 203.2 mm (8.00 in.) and 228.6 mm (9.00 in.). In both tubes, ablation increased the aft bore diameters approximately 0.38 mm (0.015 in.) and the forward bores approximately 0.15 mm (0.006 in.). The stepped launcher sustained four launches, and the straight launcher sustained five launches. After each firing, it was necessary to increase the height of the rocket shoes to compensate for lost material.

The first two launch tubes with liners (Table 2) were used to launch small diameter, high acceleration rockets. A visual examination of their bores after firing revealed no appreciable material loss and no evidence of resin melt. The bore surface finish appeared to reflect the winding mandrel finish. It is reasonable to expect that there was some material loss, but it was not apparent. These launch tubes could have been reused.

The third launcher (Table 2) was used to launch a missile with an intermediate acceleration. At the aft end of the launch tube, the rocket exhaust ablated the liner and some basic tube matrix material, exposing approximately one layer of filament. At the forward end, the liner was largely removed, but the basic tube material remained intact. There was no evidence that melting of the filaments had occurred. It appeared that some of the filament had been removed by erosion.

Table 5 groups launchers, with and without liners, that were subjected to live firings and where bore measurements were taken. All of these launchers were used to launch small diameter, high acceleration rockets (Table I, rocket No. 3, Appendix B). The launcher bores in group Nos. 1 and 2 ablated while those in group Nos. 3 and 4 apparently have resisted the ablative process. There is only one appreciable difference between the bores of these launch tubes. Those without liners have a slight waviness which appears cyclic with the winding crossover points along the tube length. This undulating bore surface will create variables involving the proximity of the nozzle exit plane diameter to the tube bore surface and the velocity of the boundary gas flow.

TABLE 5. AFT BORE MEASUREMENTS OF LAUNCH TUBES USED IN ROCKET FIRINGS

Group No.	Launcher No.	Tube Matrix Material	Liner Material	Measurement mm (in.) Before	After	Average Bore Change mm (in.)
1	A-1	Epon 828 resin NMA hardener BDMA accelerator	None	74.117 (2.918) 74.219 (2.922)	74.371 (2.928) 74.422 (2.930)	0.229 (0.009)
	A-2	Same	None	74.143 (2.919) 74.219 (2.922)	74.320 (2.926)	0.127 (0.005)
2	A-7	Epon 826 resin Tonox 6040 hardener	None	74.117 (2.918) 74.168 (2.920)	74.422 (2.930) 74.498 (2.933)	0.330 (0.013)
	A-8	Same	None	74.117 (2.918) 74.168 (2.920)	74.371 (2.928) 74.473 (2.932)	0.279 (0.011)
	A-9	Same	None	74.041 (2.915) 74.066 (2.916)	74.193 (2.921) 74.295 (2.925)	0.203 (0.008)
3	A-4	Epon 828 resin NMA hardener BDMA accelerator	Epon 828 resin TETA hardener Cab-o-sil filler	74.219 (2.922) 74.270 (2.924)	74.143 (2.919) 74.244 (2.923)	-0.051 (0.002)
	A-5	Same	Same	74.168 (2.920) 74.219 (2.922)	74.193 (2.921)	0.000
	A-6	Same	Same	74.066 (2.916) 74.219 (2.922)	73.939 (2.911) 73.990 (2.913)	-0.178 (0.007)
4	A-10	Epon 826 resin Tonox 6040 hardener	Epon 826 resin Tonox 6040 hardener Cab-o-sil filler	74.117 (2.918) 74.219 (2.922)	74.193 (2.921) 74.295 (2.925)	0.076 (0.003)
	A-11	Same	Same	74.117 (2.918) 74.168 (2.920)	74.219 (2.922) 74.270 (2.924)	0.076 (0.003)
	A-12	Same	Same	74.193 (2.921) 74.244 (2.923)	74.143 (2.919) 74.270 (2.924)	0.000

The increase in bore diameters of group No. 4 could easily be the scatter from the micrometer reading of thin-walled tubes. The negative readings of group No. 3 are more difficult to interpret. The bore changes again could be due to scatter in micrometer readings, but they could also reflect the winding filament preload on a crazed resin system in the tube wall. If the latter premise is correct, these tubes could have withstood additional rocket firings, but they could not have served as watertight protective rocket containers.

2. Plasma Gun Tests

The tube sections forwarded under the Brunswick contract were cut into approximately 51 mm (2.0 in.) square test specimens and tested under conditions previously described. Four tube material combinations were eliminated from further consideration (Tables 3 and 4, tube Nos. 002, 003, 006, and 012). The base line tube section (Table 3, tube No. 015) is also considered unsuitable, but will be included in subsequent tests for comparative purposes. These test specimens showed severe damage under the "heat" test condition. The remainder of the material combinations survived the "heat" test condition to some degree.

The effects from the test conditions imposed by the plasma gun on the remaining specimens are shown in Appendix A (Figures A-2 through A-9). Table 6 is a synopsis resulting from a visual examination of each specimen with a correlation to the respective figures. In addition, a weight evaluation was attempted (Tables 7 and 8). The weight evaluation, if considered by itself, could be misleading. If one compares weight losses, it appears that those tube sections without liners are the most desirable. In actuality, the resin matrix was ablated from the filaments, thus permitting them to form a protective layer preventing further ablation.

IV. CONCLUSIONS

Tube-launched rockets generate considerable initial bore surface heating in the aft portion of the launch tubes. The rocket exhaust continues to heat this area for the time interval between ignition and when the rocket clears the launcher. In some instances, heating will continue for a short time after the rocket has left the launcher. The matrix resins currently being used in filament-wound composites are susceptible to sustained high temperatures and erosion. Consequently, the rapidity with which a rocket having aluminized propellant is launched will ultimately determine the degree of reusability for a filament-wound composite launch tube.

In the live firing tests using small diameter, high acceleration, fast burn rockets, the launch tubes with liners apparently did not ablate (Tables 2 and 5). These launch tubes are considered reusable.

TABLE 6. PLASMA GUN TEST RESULTS

Tube Specimen No.	Figure No.	With/Without Liner	Magnified Surface (X10)*	Test Condition	Remarks
013	A-2	With	Figure A-2(a)		Original tube bore surface.
			Figure A-2(b)	Heat	Slight removal of liner material. Roughened and dull surface finish. Appears to be a slight amount of heat checking.
			Figure A-2(c)	Heat plus grit	Increased amount of liner material removed. Small areas of the basic tube material exposed. Increase in amount of heat checking.
			Figure A-2(d)	High heat	This test condition was destructive, liner material was completely removed. Removed resin matrix in approximately 2 layers of the basic tube. Filament charred with some filament removal.
014	A-3	With	Figure A-3(a)	—	Original tube bore surface.
			Figure A-3(b)	Heat	Most of the liner material removed. Spotty exposure of filaments in the basic tube. Darkened impingement surface. Filaments in basic tube intact.
			Figure A-3(c)	Heat plus grit	Appearance similar to the heat condition. Further exposure of filaments in the basic tube. Filaments in basic tube still intact.
			Figure A-3(d)	High heat	Test condition was destructive. Liner material completely removed. Removed resin matrix in approximately 2 layers of the basic tube. Filament charred with some filament removal.
015	A-4	Without	Figure A-4(a)	—	Original tube bore surface.
			Figure A-4(b)	Heat	Removed resin matrix for a depth of approximately 1-1/2 layers with free filament exposed on surface. Some filament separation. Severe discoloration of resin matrix.
			Figure A-4(c)	Heat plus grit	Similar in appearance to the heat condition. Resin matrix removal approximately 1-1/2 layers deep. Free filament exposed on surface. Some fading of the discoloration.

*Figures contained in Appendix A.

TABLE 6. (Continued)

Tube Specimen No.	Figure No.	With/Without Liner	Magnified Surface (X10)*	Test Condition	Remarks
015	A-4	Without	Figure A-4(d)	High heat	Heavy charring through approximately 1/2 of wall thickness (2 layers). Some filament melt and removal.
017	A-5	With	Figure A-5(a)	—	Original tube bore surface.
			Figure A-5(b)	Heat	Most of liner removed. Spotted baring of the basic tube material. The spots follow along the wrap angle. Dulling and roughening of the surface.
			Figure A-5(c)	Heat plus grit	Most of liner removed. Appearance is similar to the heat condition except spots are larger. Some heat checking. Dulling and roughening of the surface.
			Figure A-5(d)	High heat	Complete removal of the liner and basic tube matrix material for approximately 1-1/2 layers. Exposed filaments are charred with a small amount of filament removal.
019	A-6	Without	Figure A-6(a)	—	Original tube bore surface.
			Figure A-6(b)	Heat	Small amount of resin matrix removal. Darkening and roughening of surface.
			Figure A-6(c)	Heat plus grit	Resin matrix removal approximately 1 layer deep. Surface darkening. No filament displacement.
			Figure A-6(d)	High heat	Complete removal of resin matrix. Approximately 1 layer deep. Complete charring of filament within this layer. Some filament removal.
020	A-7	With	Figure A-7(a)	—	Original tube bore surface.
			Figure A-7(b)	Heat	Appears to be some resin removal but liner still intact. Surface is rough, granular, and darkened.
			Figure A-7(c)	Heat plus grit	Increased resin removal, liner still intact. Surface roughness and granular appearance increased. Darkening is similar to the heat condition.

*Figures contained in Appendix A.

TABLE 6. (Concluded)

Tube Specimen No.	Figure No.	With/Without Liner	Magnified Surface (X10)*	Test Condition	Remarks
020	A-7	With	Figure A-7(d)	High heat	Charred blistering of liner material. Spotted removal of liner material exposing basic tube material. Remainder of surface is rough, granular, and darkened.
021	A-8	With	Figure A-8(a)	—	Original tube bore surface.
			Figure A-8(b)	Heat	Removal of most of the liner material. Remainder darkened. Zebra-like appearance. Stripes are the exposed surface of the basic tube and follow wrap angles.
			Figure A-8(c)	Heat plus grit	Removal of most of the liner; remainder darkened. Zebra-like appearance stripes more pronounced. Stripes are the exposed surface of the basic tube and follow the wrap angles.
			Figure A-8(d)	High heat	Complete removal of the liner material. Removal of basic tube resin matrix for approximately 1 layer deep. Charring of filament with some blown away.
022	A-9	With	Figure A-9(a)	—	Original tube bore surface.
			Figure A-9(b)	Heat	Most of liner material removed. Pitting of basic tube resin matrix approximately 1/2 layer deep. Appears to be some resin melting. Surface darkened.
			Figure A-9(c)	Heat plus grit	All liner material removed. Deep pitting of basic tube resin matrix for approximately 1 layer deep. Appears to be resin melting. Surface darkening.
			Figure A-9(d)	High heat	Complete removal of liner material and basic tube resin matrix for approximately 1-1/2 layers. Heavy charring of filament with some removed.

*Figures contained in Appendix A.

TABLE 7. WEIGHT LOSS OF FILAMENT-WOUND COMPOSITE TEST SPECIMENS WITH LINERS* — THREE TEST CONDITIONS

Tube No.**	Test Condition	Specimen Weight (grams)†		Weight Loss (grams)	Weight Loss (%)
		Before	After		
006	Heat	7.6456	7.3295	0.3160	4.14
	Heat with grit	7.4466	7.0545	0.3921	5.27
	High heat	7.5447	6.4613	1.0835	14.37
013	Heat	7.0783	6.8174	0.2609	3.69
	Heat with grit	6.8839	6.6205	0.2635	3.84
	High heat	7.1392	6.4217	0.7175	10.05
014	Heat	7.1086	6.8261	0.2825	3.98
	Heat with grit	7.3051	7.0560	0.2491	3.41
	High heat	7.3047	6.4659	0.8388	11.47
017	Heat	7.7726	7.6428	0.1338	1.71
	Heat with grit	7.8693	7.6650	0.2043	2.60
	High heat	7.7567	6.9134	0.8433	10.87
020	Heat	8.1421	7.8514	0.2907	3.58
	Heat with grit	8.0025	7.5522	0.4503	5.69
	High heat	8.1737	7.3995	0.7742	9.47
021	Heat	7.2341	7.0246	0.8096	2.90
	Heat with grit	7.1445	6.8781	0.2664	3.73
	High heat	7.1695	6.2921	0.8774	12.24
022	Heat	6.7643	6.5575	0.2068	3.06
	Heat with grit	6.9200	6.6368	0.2831	4.09
	High heat	6.8597	6.1002	0.7595	11.07

*Reference Table 8 for specimens having the baseline tube construction.

†Specimen weight is the average weight of five test specimens.

**Specimens cut from filament-wound tube sections having these identification numbers.

TABLE 8. WEIGHT LOSS OF FILAMENT-WOUND COMPOSITE TEST SPECIMENS WITHOUT LINERS — THREE TEST CONDITIONS

Tube No.*	Test Condition	Specimen Weight (grams)**		Weight Loss (grams)	Weight Loss (%)
		Before	After		
002	Heat	6.7326	6.6234	0.1091	1.62
	Heat with grit	6.6709	6.5504	0.0964	1.44
	High heat	7.1504	6.5275	0.6229	8.71
003	Heat	6.8526	6.7627	0.0899	1.31
	Heat with grit	6.9320	6.7975	0.1346	1.94
	High heat	6.6362	6.2142	0.4220	6.36
012	Heat	6.8241	6.7821	0.0421	0.62
	Heat with grit	6.8140	6.7645	0.0495	0.73
	High heat	6.9718	6.2251	0.7467	10.71
015†	Heat	7.6144	7.4691	0.1453	1.91
	Heat with grit	7.6898	7.5618	0.1280	1.67
	High heat	7.7191	7.0652	0.6539	8.48
019	Heat	7.8492	7.6163	0.2329	2.97
	Heat with grit	7.9506	7.7708	0.1798	2.26
	High heat	7.9656	7.3692	0.5964	7.49

*Specimens cut from filament-wound tube sections having these identification numbers.

**Specimen weight is the average weight of five test specimens.

†Specimens cut from tube having the baseline construction.

Those launchers without liners and used under the same conditions did ablate. It seems that the undulating bore surface of these launch tubes contributed greatly to the ablative process. The exhaust from the larger diameter rocket with a slower acceleration and a longer burn time ablated away the bore surface matrix material of all the composite launch tubes (with and without liners) used in the live firings (Tables 1 and 2). The exposure of the basic tube filament prevents any consideration for reusability in a tactical sense.

Because ablation occurred on all specimens in the plasma gun tests, the analysis presented is invalid for design purposes. However, it does give an indication of the specimen bore surface temperatures resulting from plasma gun applied heat. The environment imposed on the specimens

with the plasma gun was more severe than that imposed by Brunswick with the oxyacetylene torch. As a result of the dual step qualitative assessment, several liner material combinations are selected for further evaluation. These have tube section Nos. 013, 017, 021, and 022. Also, the liner material combination of Epon 828/TETA with Cab-o-sil filler, which withstood the live firing environment, should be included. The proprietary resin system used in tube section No. 019 needs further evaluation. Indications were that it would serve as a liner material along with the other selected material combinations.

V. RECOMMENDATIONS

The results, to date, indicate that a cost effective filament-wound reusable launch tube can be fabricated that would resist the effects from an aluminized propellant exhaust. Because of the many variables involved, the ultimate "follow-on" program would involve full size rockets and launch tubes. Because this is impractical, it is recommended that the proposed intermediate step using scaled motors and filament-wound tubes be initiated. It is further recommended that additional qualitative evaluations using other material combinations be undertaken.

Appendix A.

PLASMA GUN TEST SPECIMEN PHOTOGRAPHS

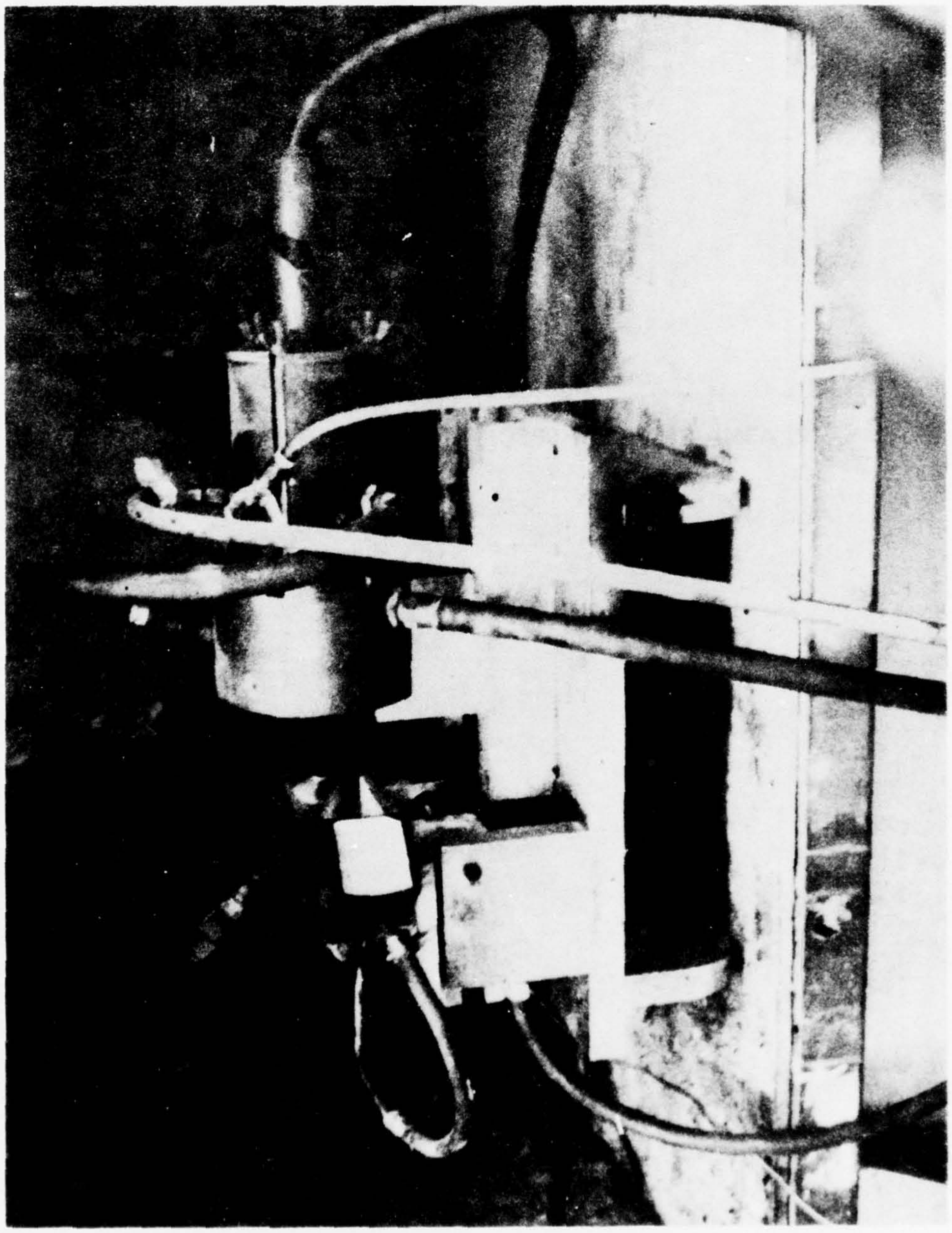


Figure A-1. Plasma gun test fixture.

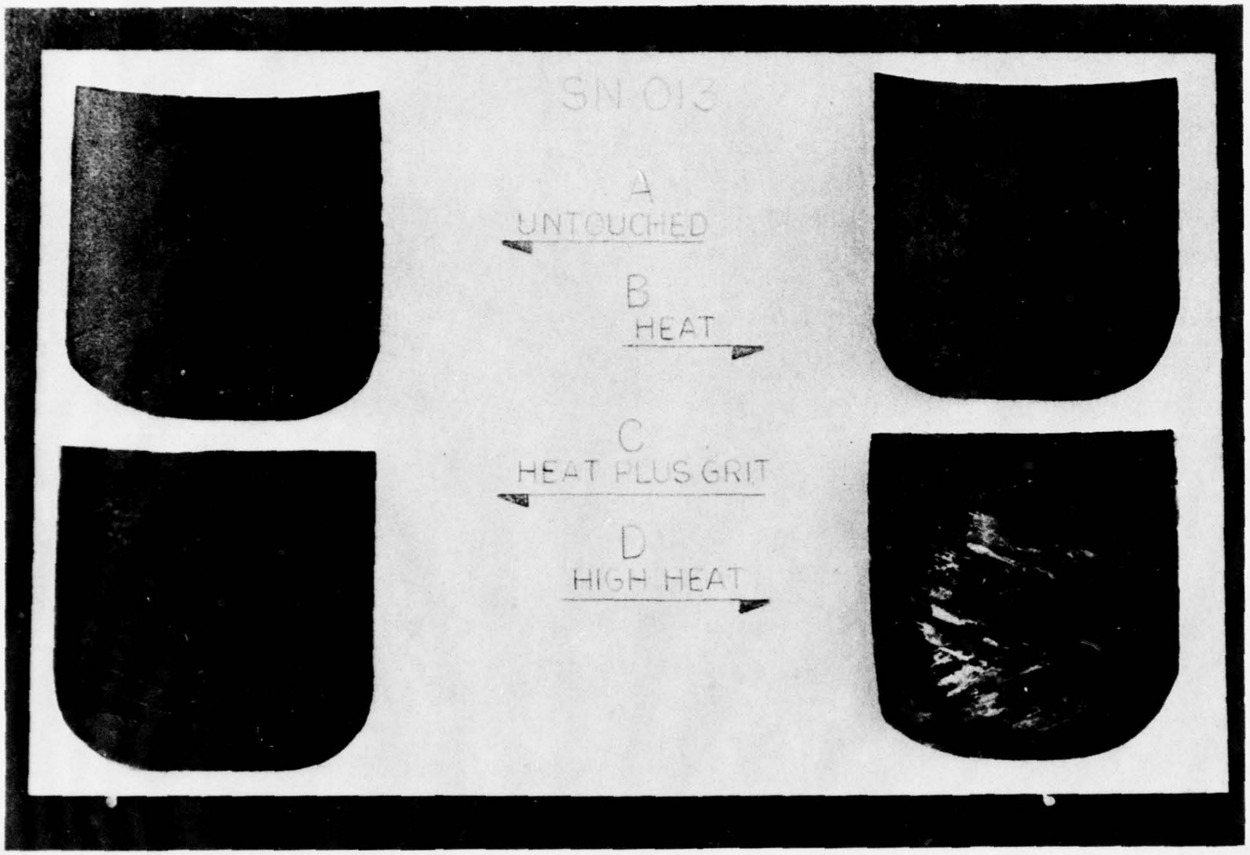
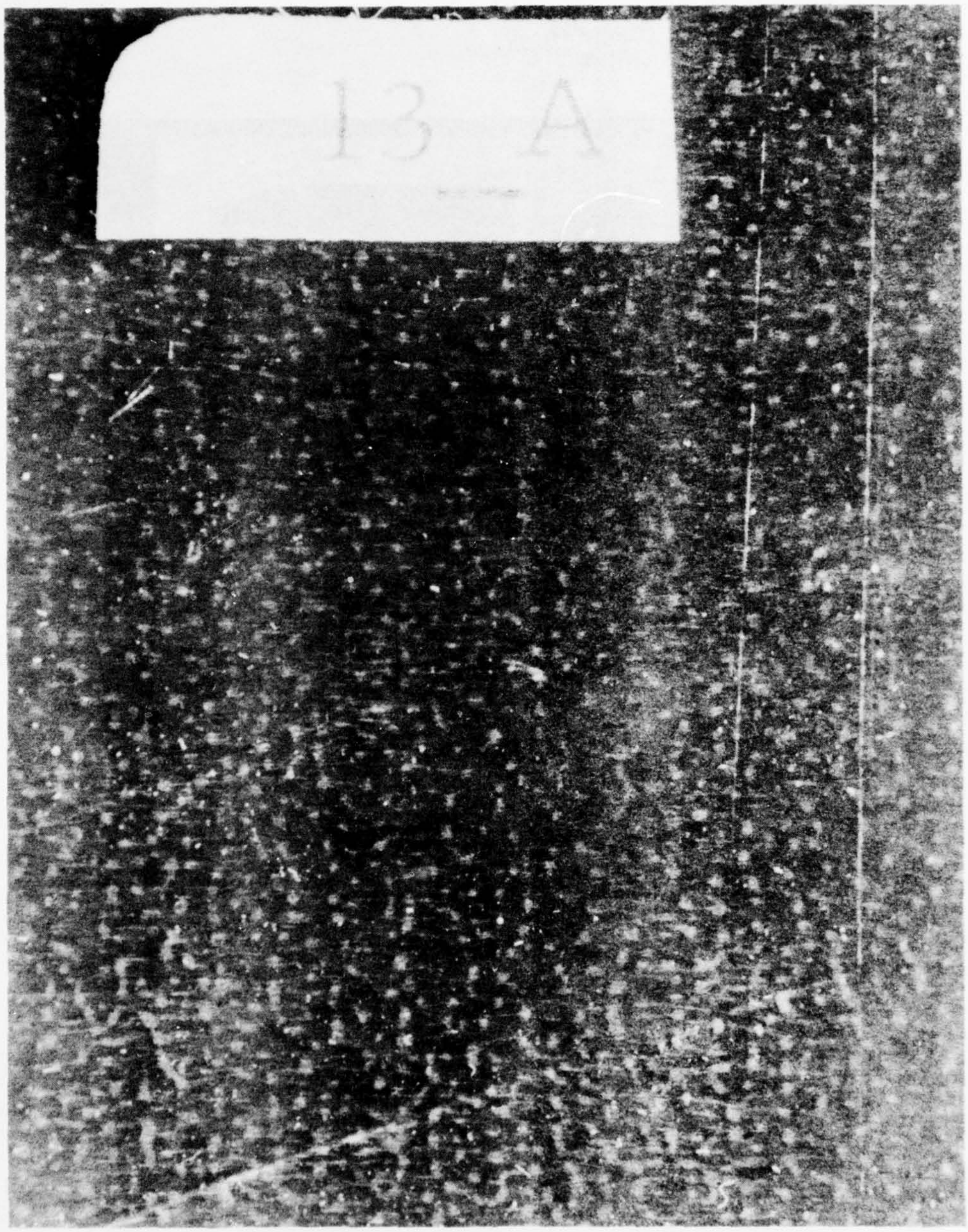
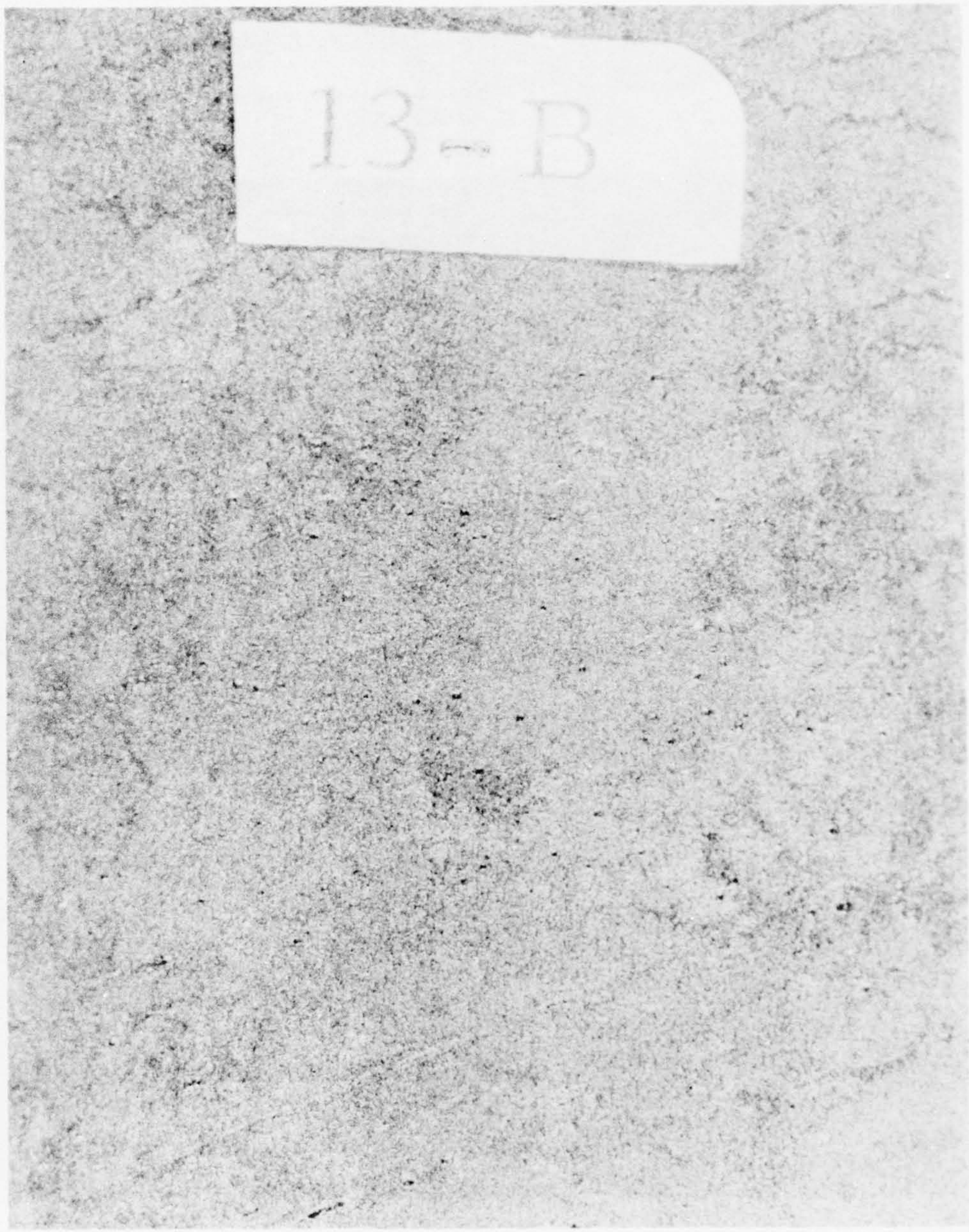


Figure A-2. Test specimens cut from tube section 013.



(a) ORIGINAL TUBE BORE SURFACE (X10)

Figure A-2. (Continued).

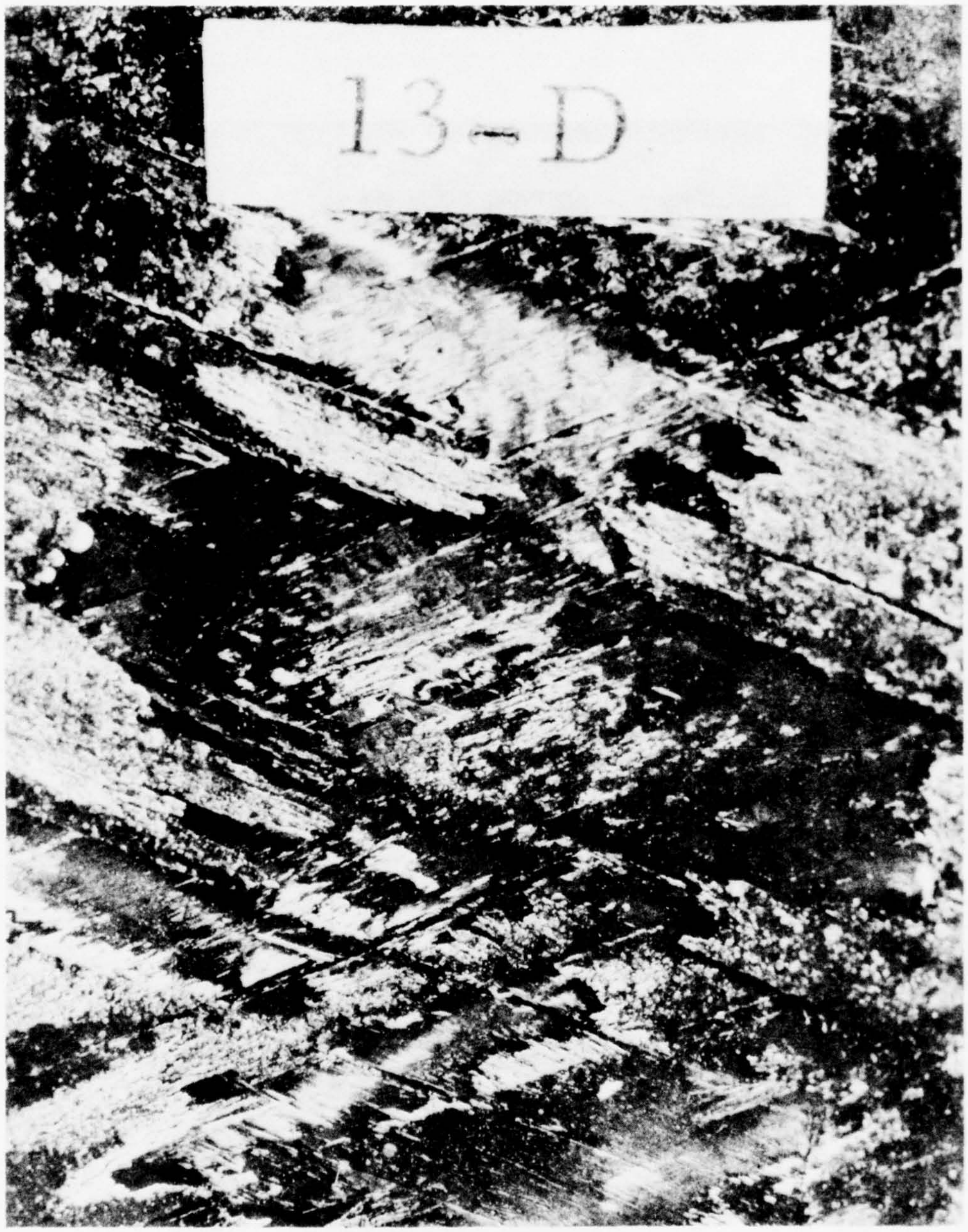


(b) BORE SURFACE AFTER APPLICATION OF HEAT TEST CONDITION (X10)

Figure A-2. (Continued).

(c) BORE SURFACE AFTER APPLICATION OF HEAT PLUS GRIT TEST CONDITION (X10)

Figure A-2. (Continued).



(d) BORE SURFACE AFTER APPLICATION OF HIGH HEAT TEST CONDITION (X10)

Figure A-2. (Concluded).

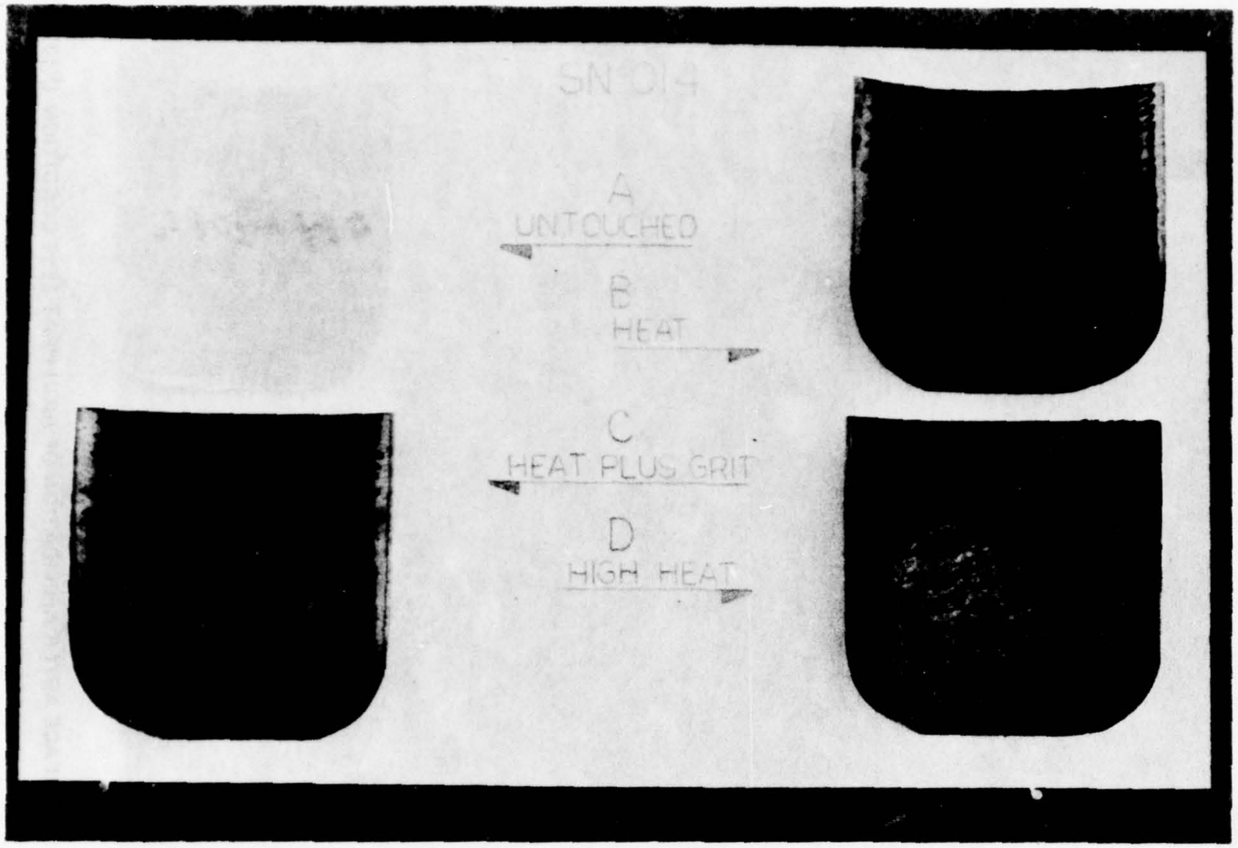
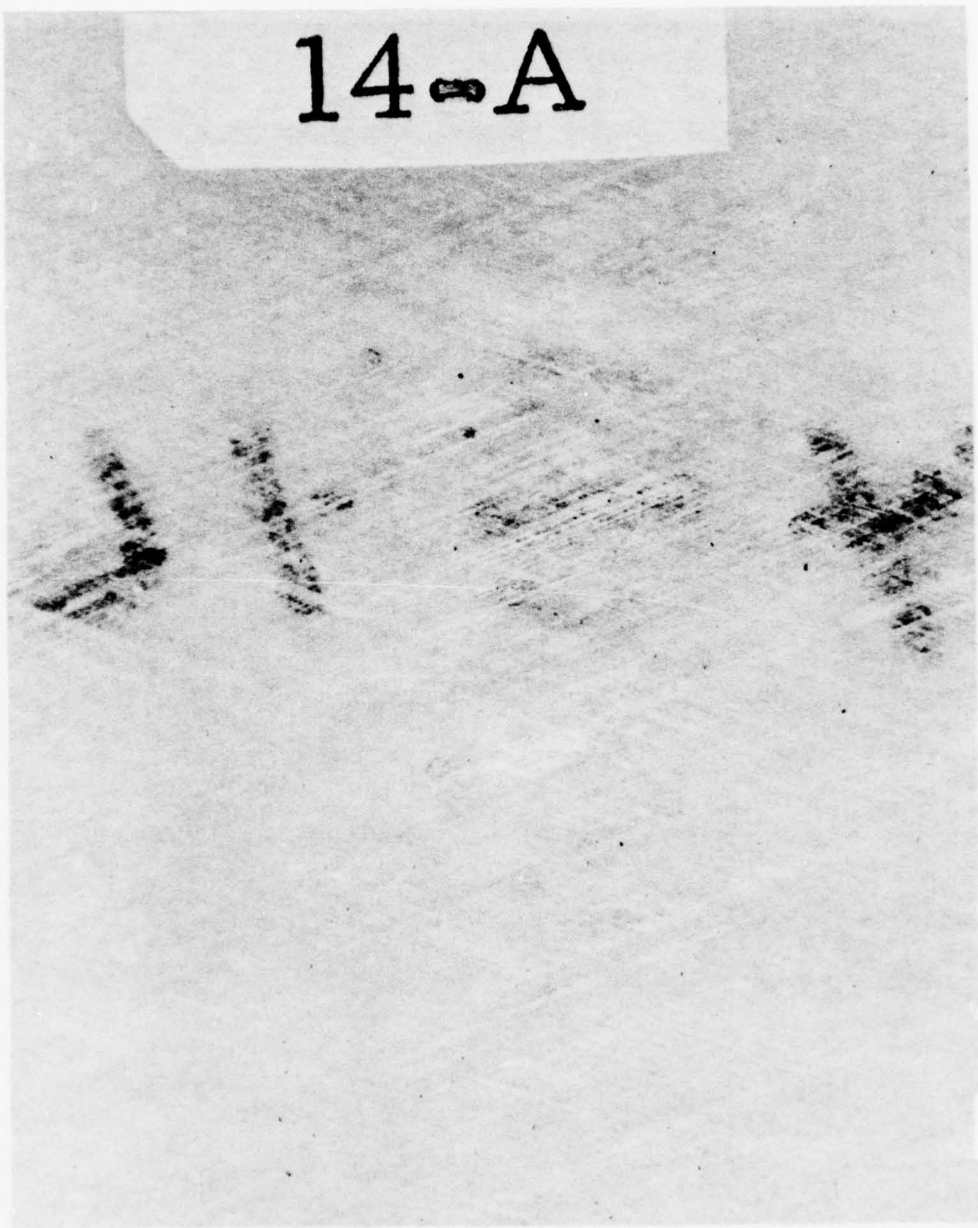
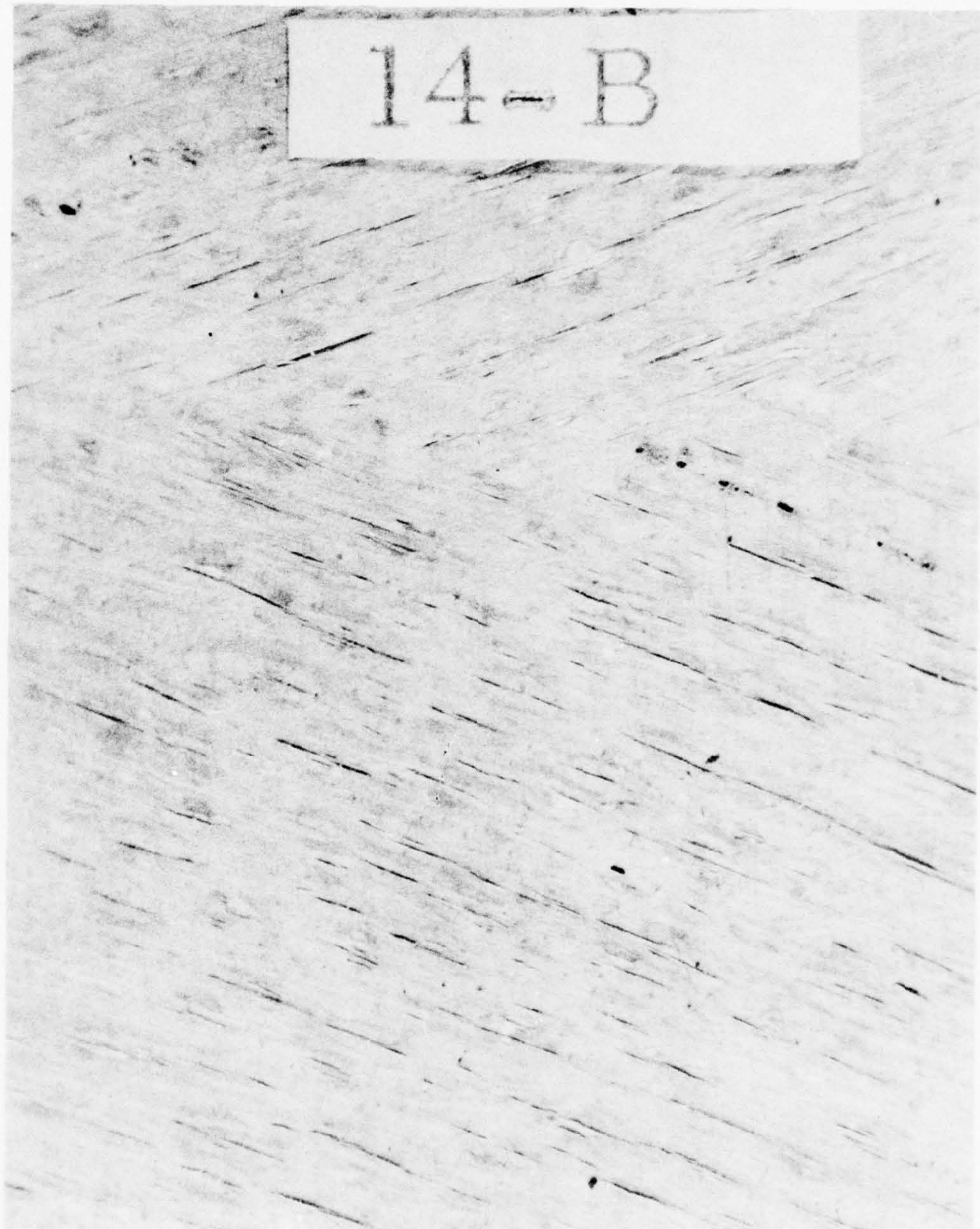


Figure A-3. Test specimens cut from tube section 014.



(a) ORIGINAL TUBE BORE SURFACE (X10)

Figure A-3. (Continued).



(b) BORE SURFACE AFTER APPLICATION OF HEAT TEST CONDITION (X10)

Figure A-3. (Continued).

(c) BORE SURFACE AFTER APPLICATION OF HEAT PLUS GRIT TEST CONDITION (X10)

Figure A-3. (Continued).

(d) BORE SURFACE AFTER APPLICATION OF HIGH HEAT TEST CONDITION (X10)

Figure A-3. (Concluded).

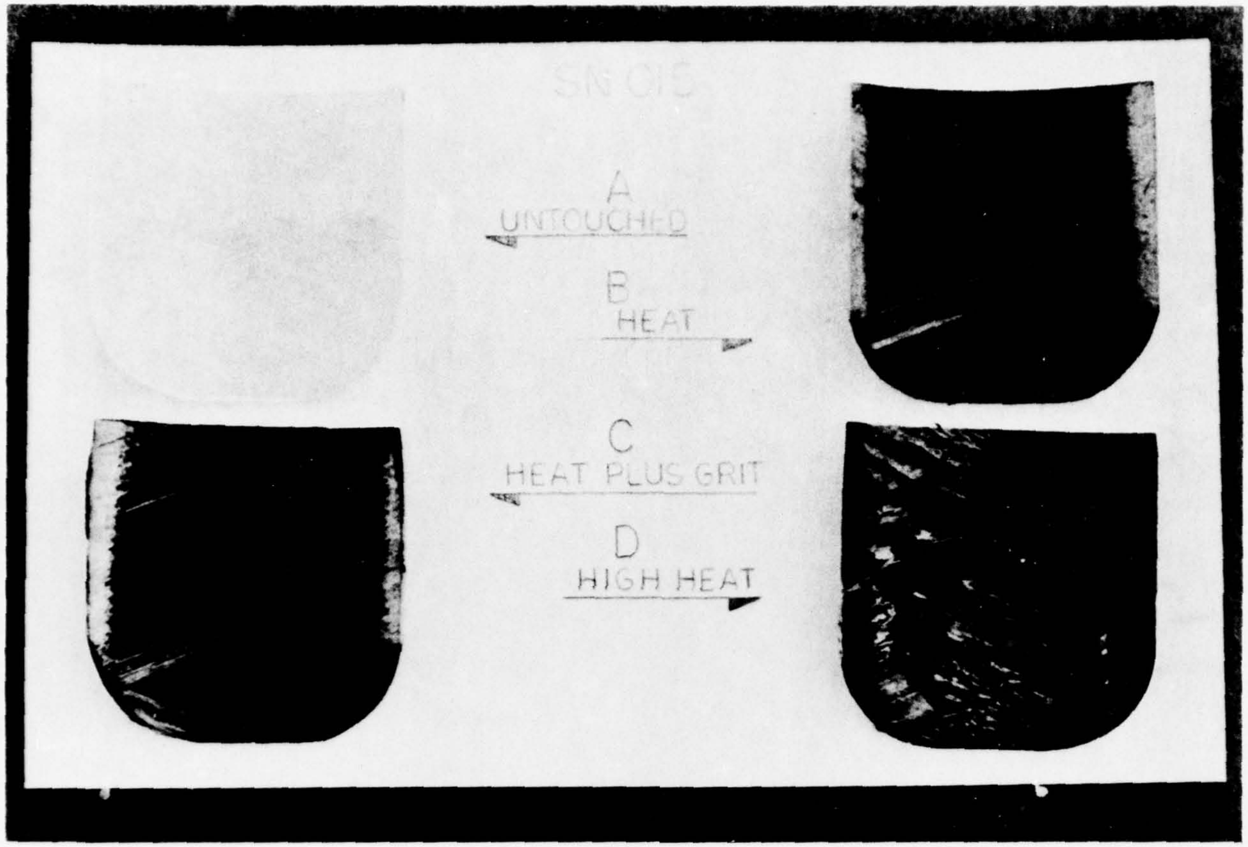
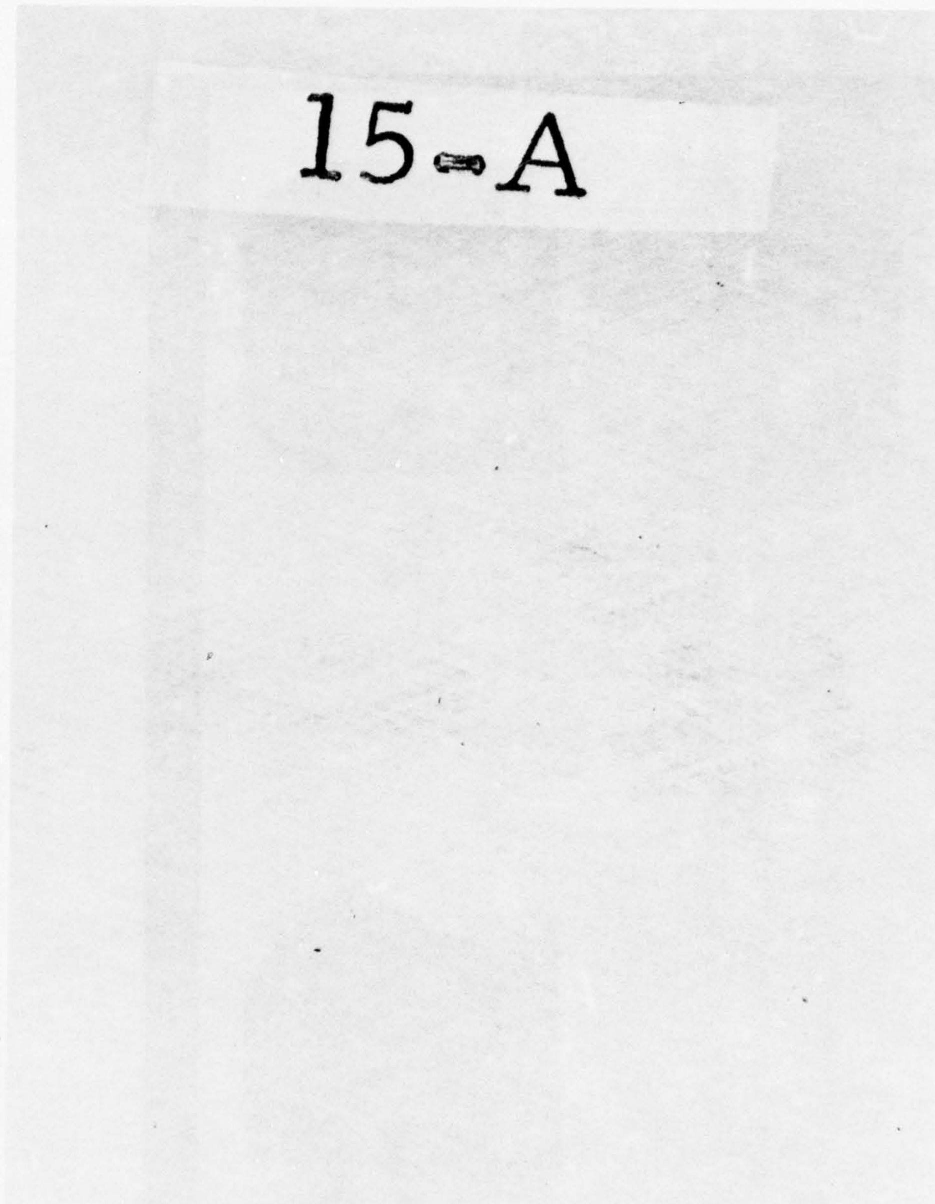


Figure A-4. Test specimens cut from tube section 015.



(a) ORIGINAL TUBE BORE SURFACE (X10)

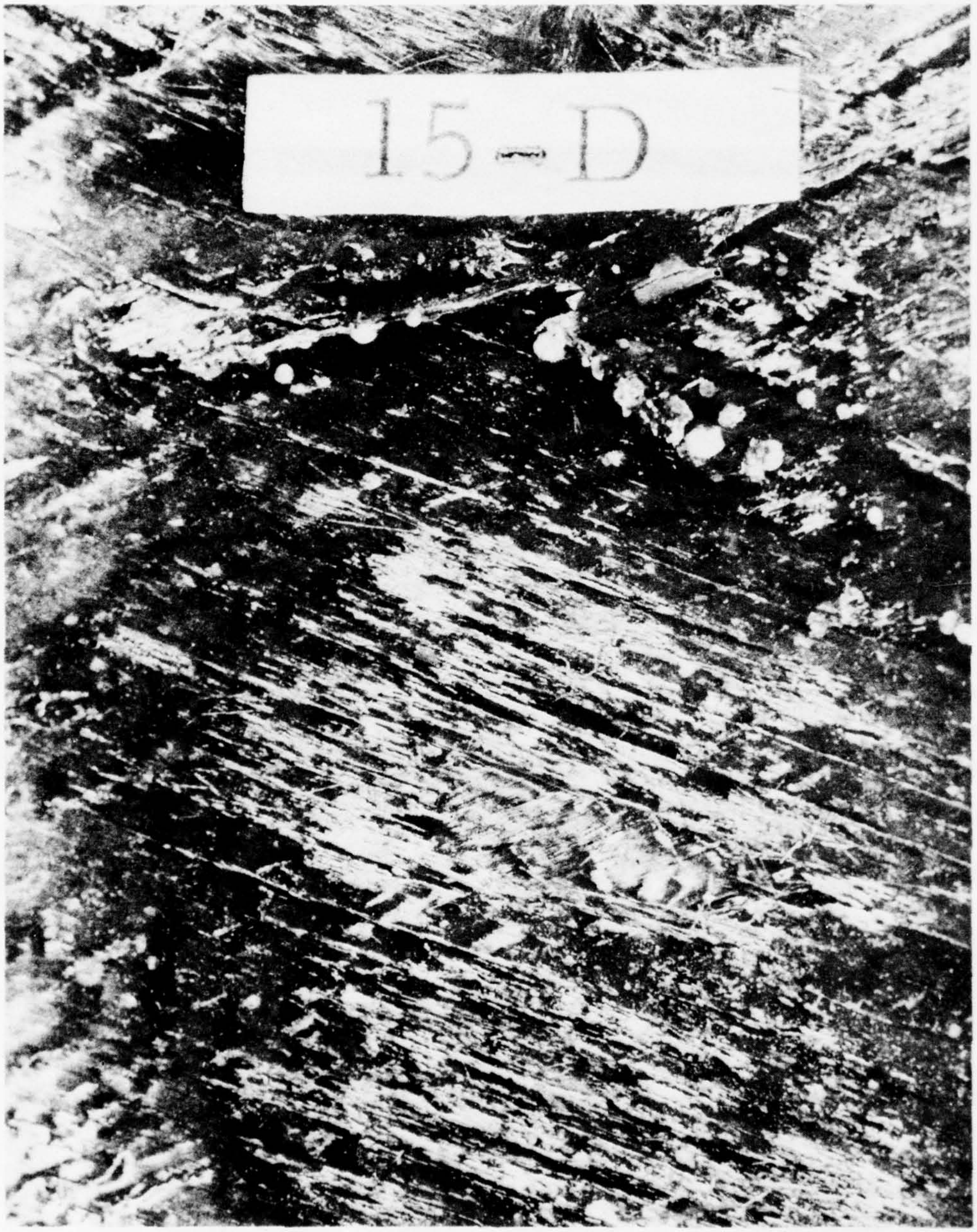
Figure A-4. (Continued).

(b) BORE SURFACE AFTER APPLICATION OF HEAT TEST CONDITION (X10)

Figure A-4. (Continued).

(c) BORE SURFACE AFTER APPLICATION OF HEAT PLUS GRIT TEST CONDITION (X10)

Figure A-4. (Continued).



(d) BORE SURFACE AFTER APPLICATION OF HIGH HEAT TEST CONDITION (X10)

Figure A-4. (Concluded).

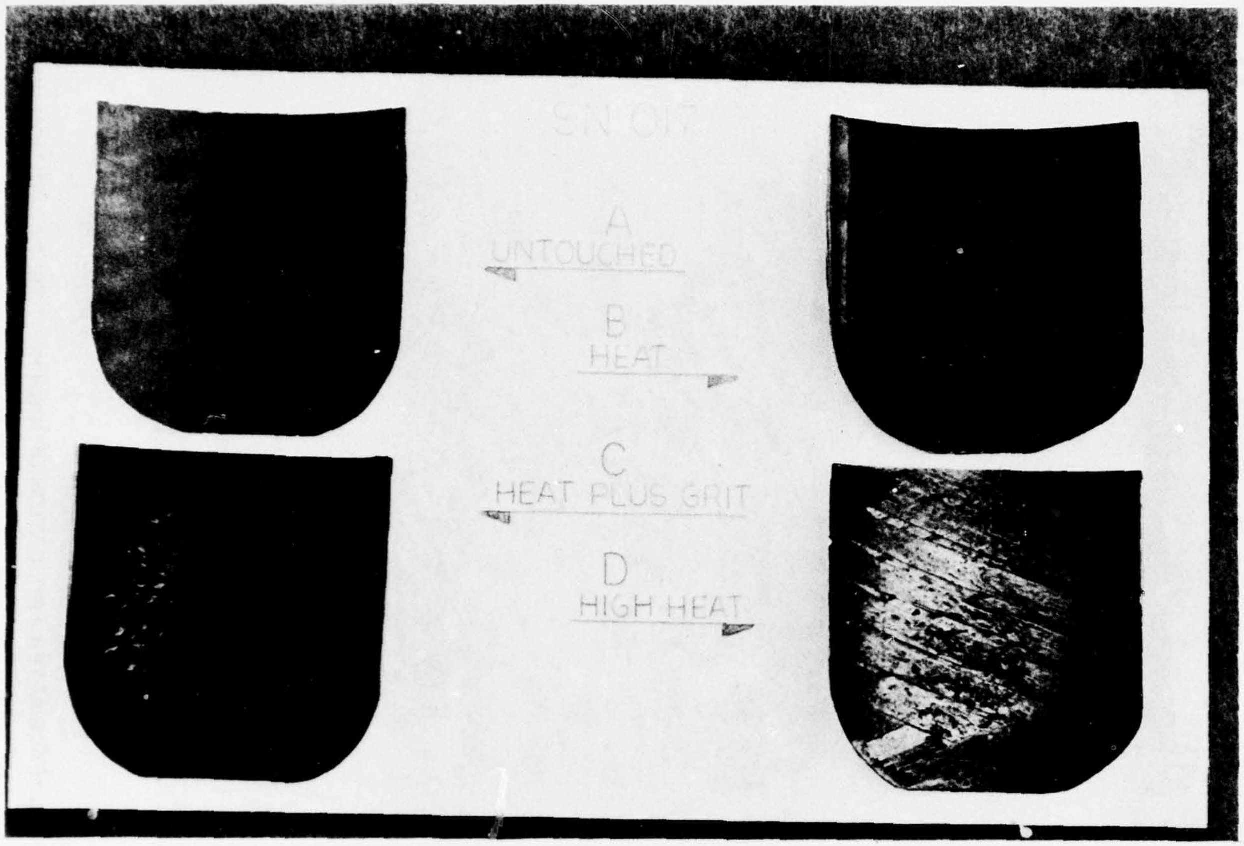
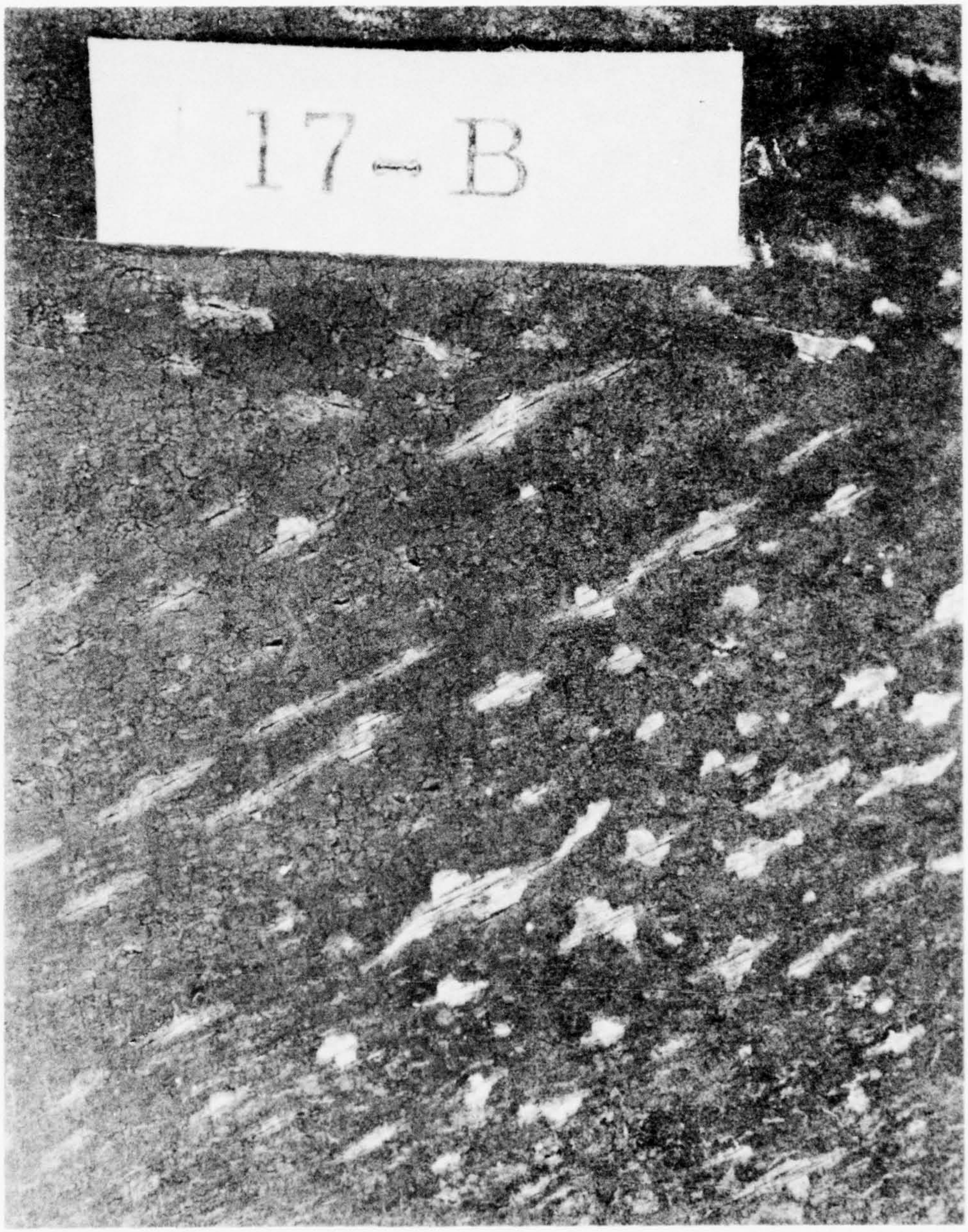


Figure A-5. Test specimens cut from tube section 017.

(a) ORIGINAL TUBE BORE SURFACE (X10)

Figure A-5. (Continued).

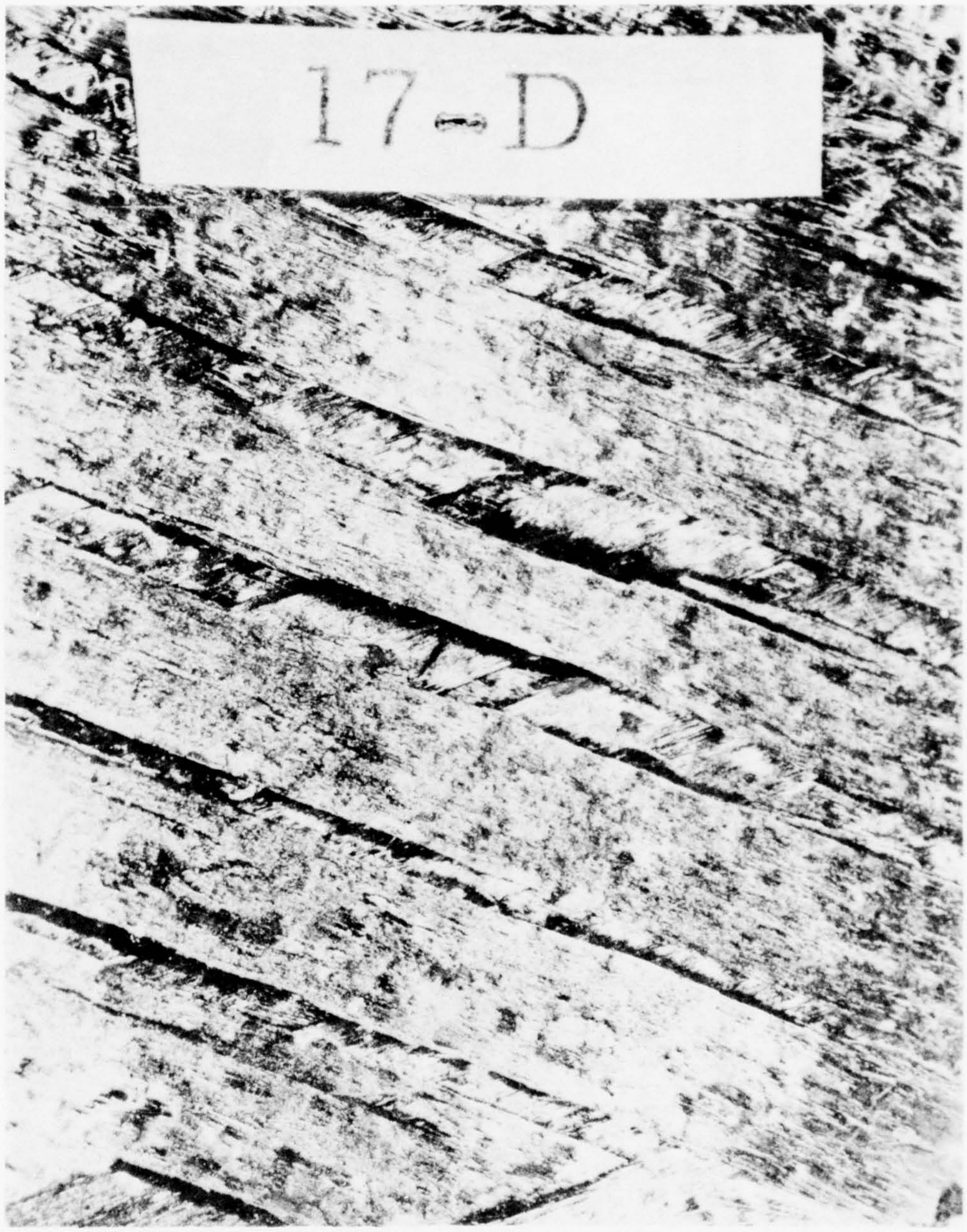


(b) BORE SURFACE AFTER APPLICATION OF HEAT TEST CONDITION (X10)

Figure A-5. (Continued).

(c) BORE SURFACE AFTER APPLICATION OF HEAT PLUS GRIT TEST CONDITION (X10)

Figure A-5. (Continued).



(d) BORE SURFACE AFTER APPLICATION OF HIGH HEAT TEST CONDITION (X10)

Figure A-5. (Concluded).

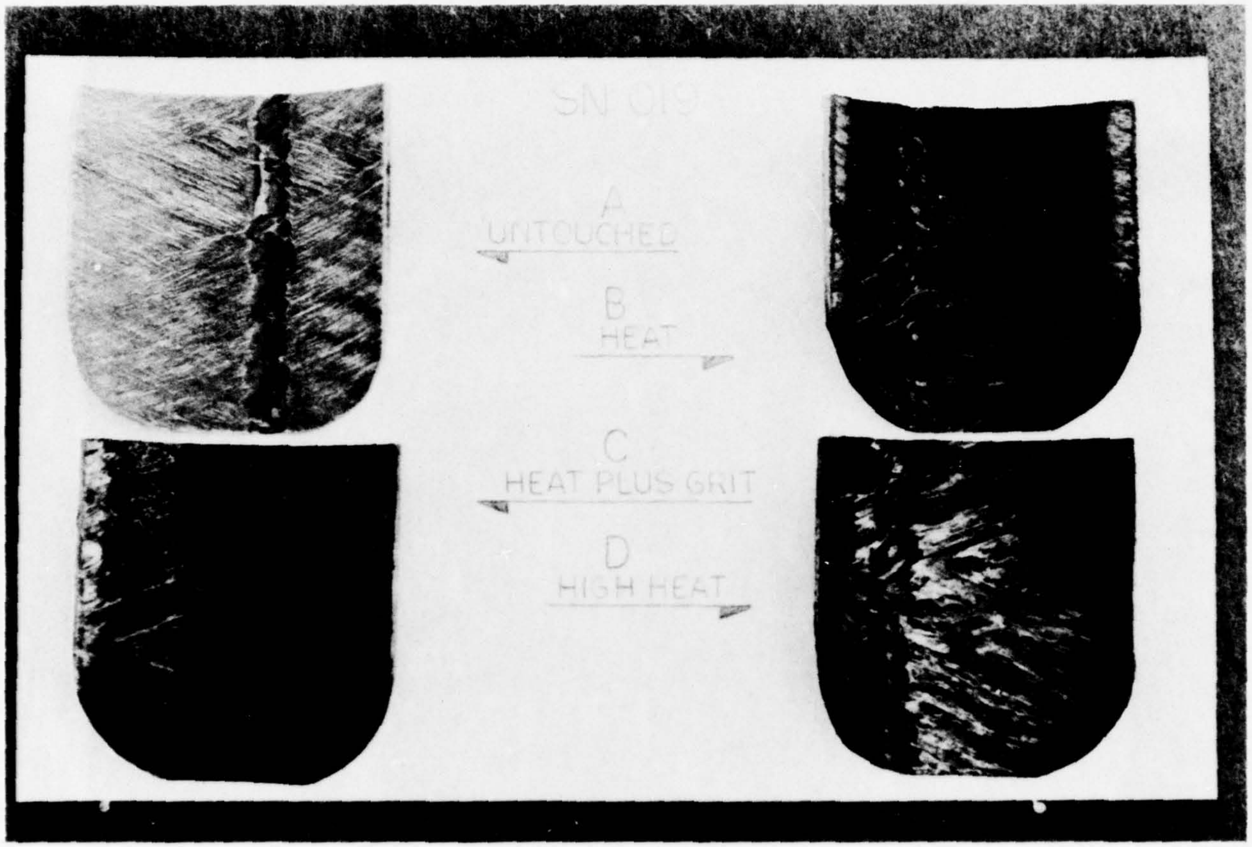
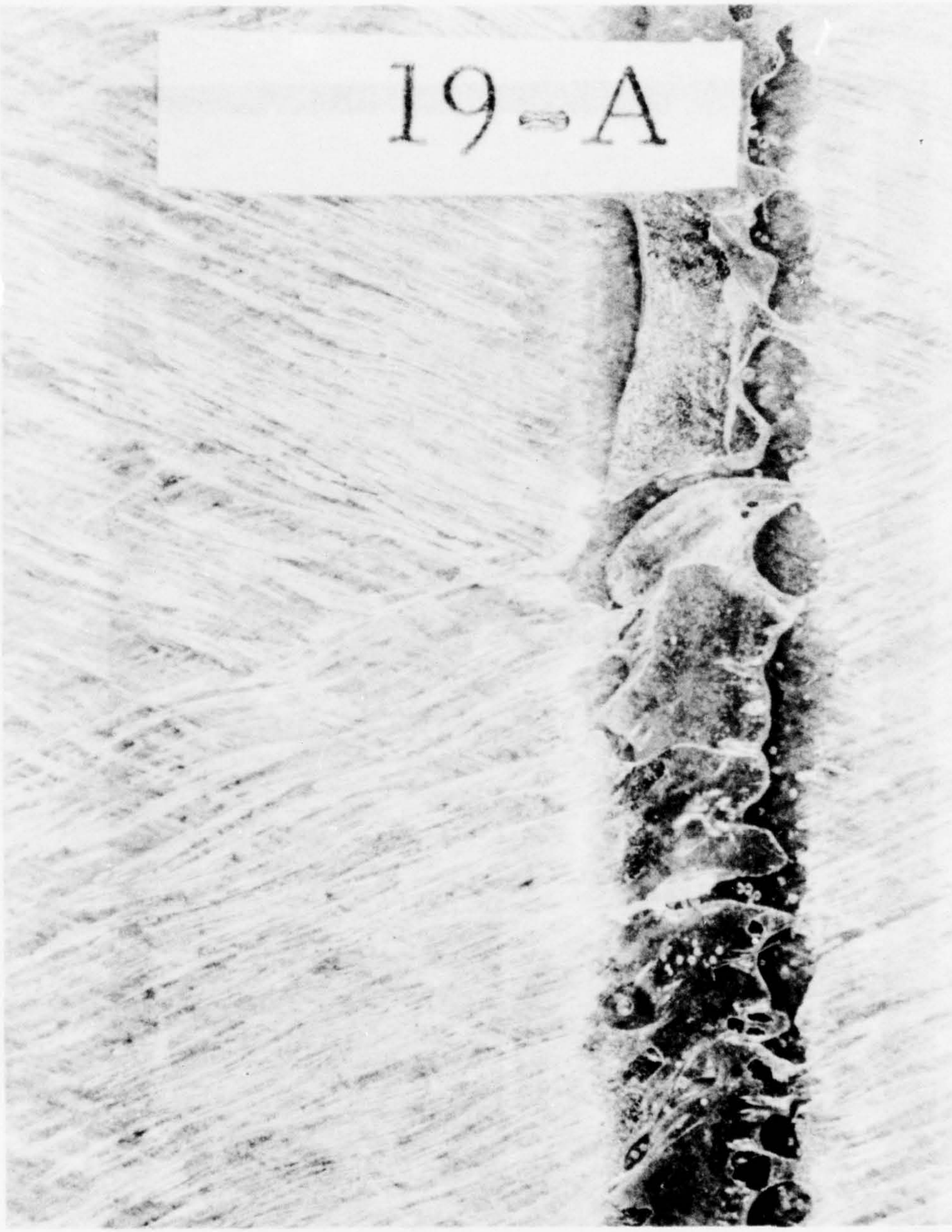
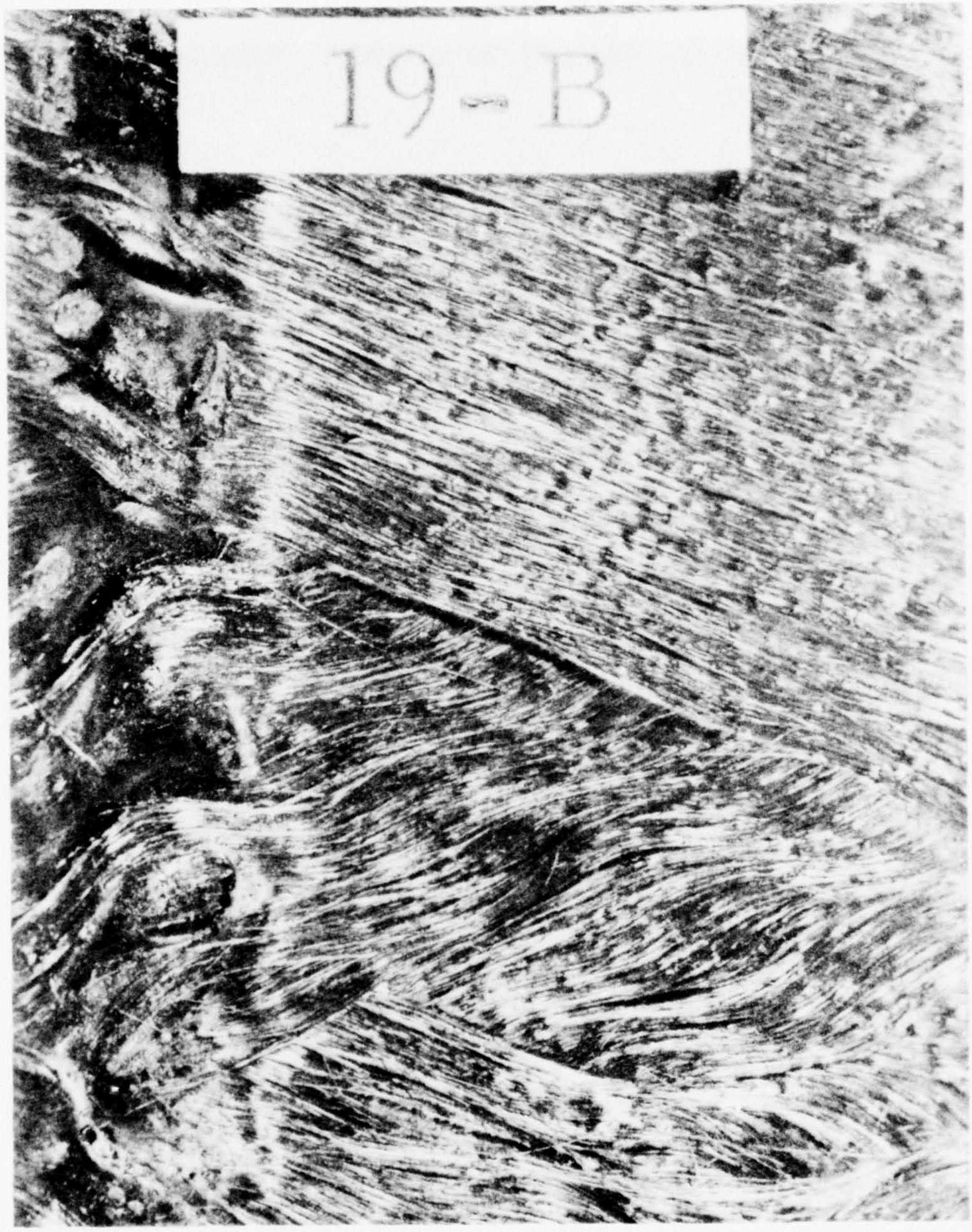


Figure A-6. Test specimens cut from tube section 019.



(a) ORIGINAL TUBE BORE SURFACE (X10)

Figure A-6. (Continued).

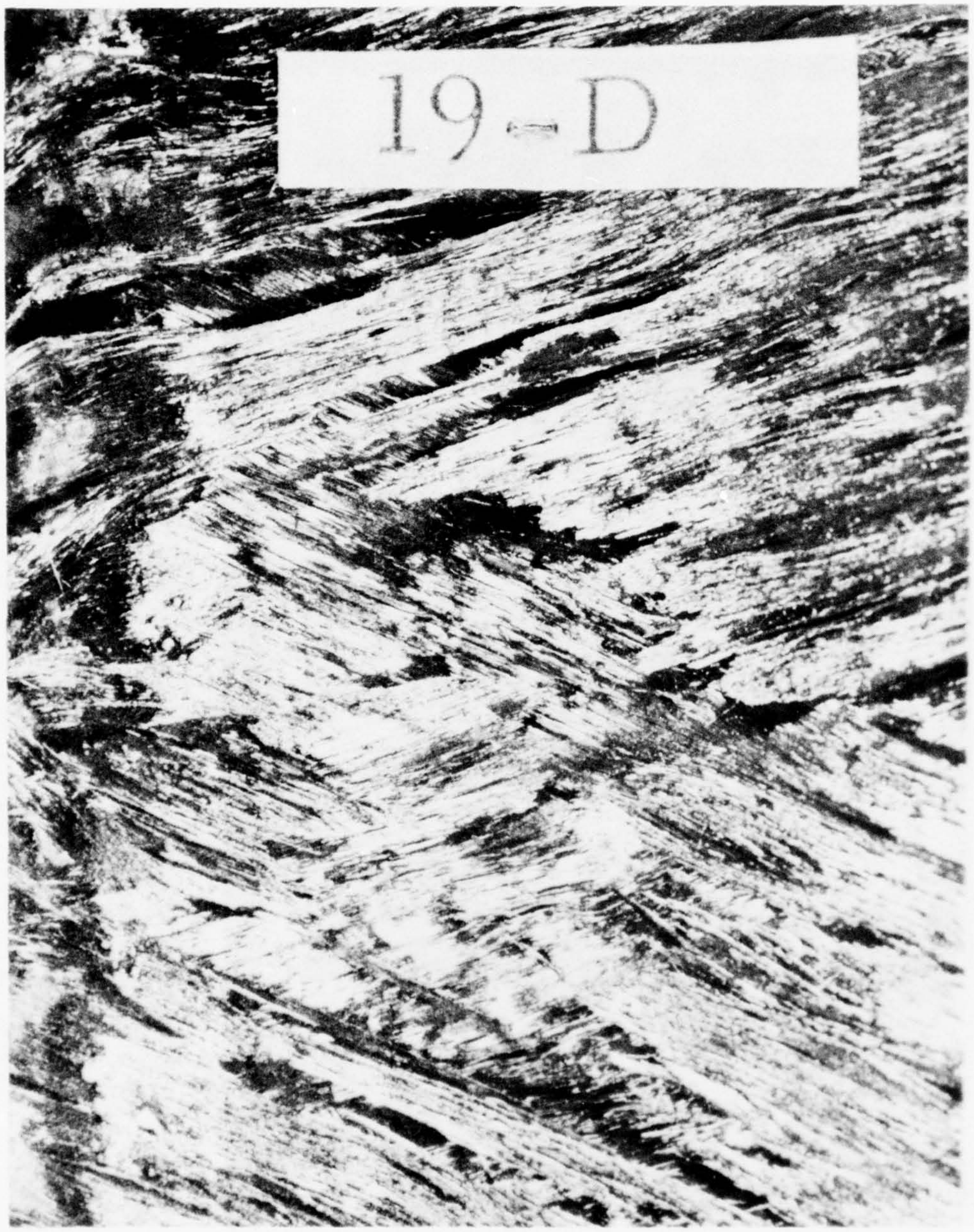


(b) BORE SURFACE AFTER APPLICATION OF HEAT TEST CONDITION (X10)

Figure A-6. (Continued).

(c) BORE SURFACE AFTER APPLICATION OF HEAT PLUS GRIT TEST CONDITION (X10)

Figure A-6. (Continued).



(d) BORE SURFACE AFTER APPLICATION OF HIGH HEAT TEST CONDITION (X10)

Figure A-6. (Concluded).

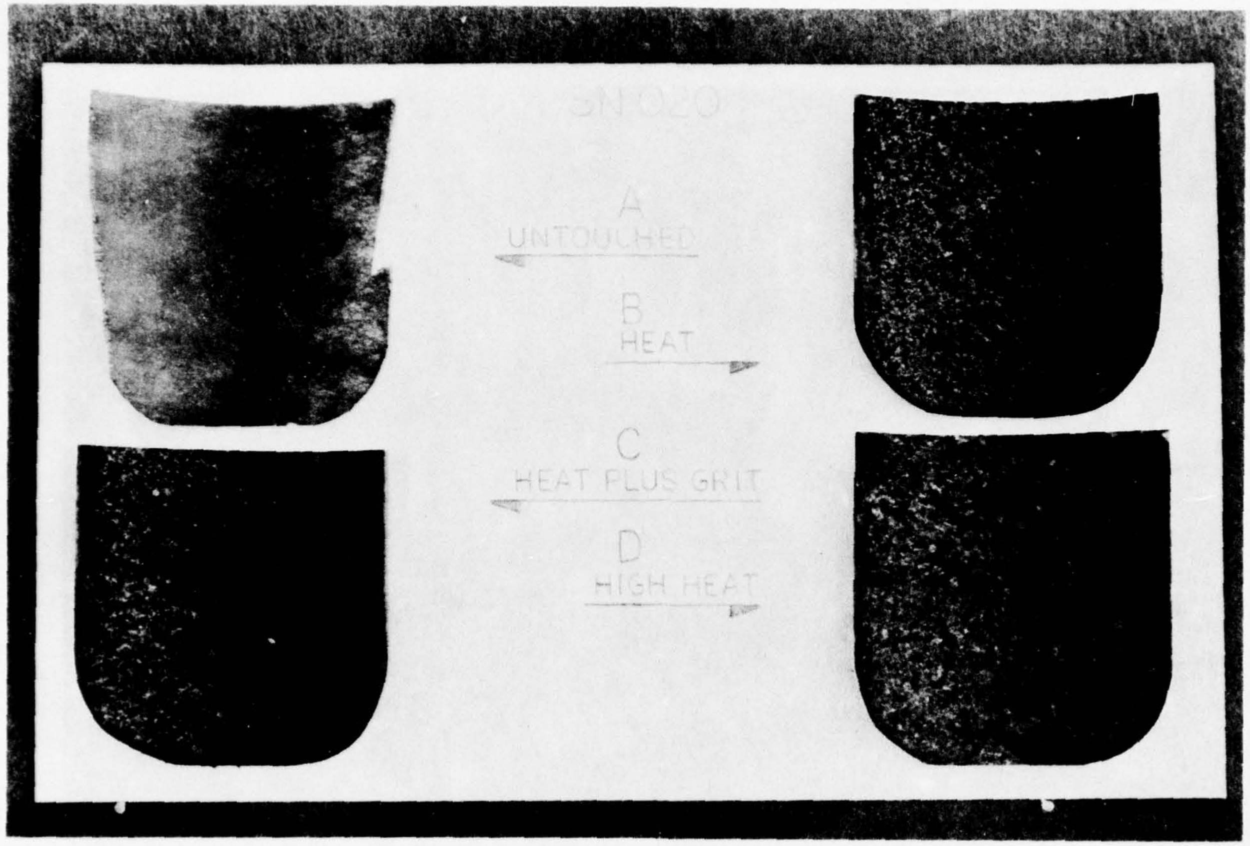
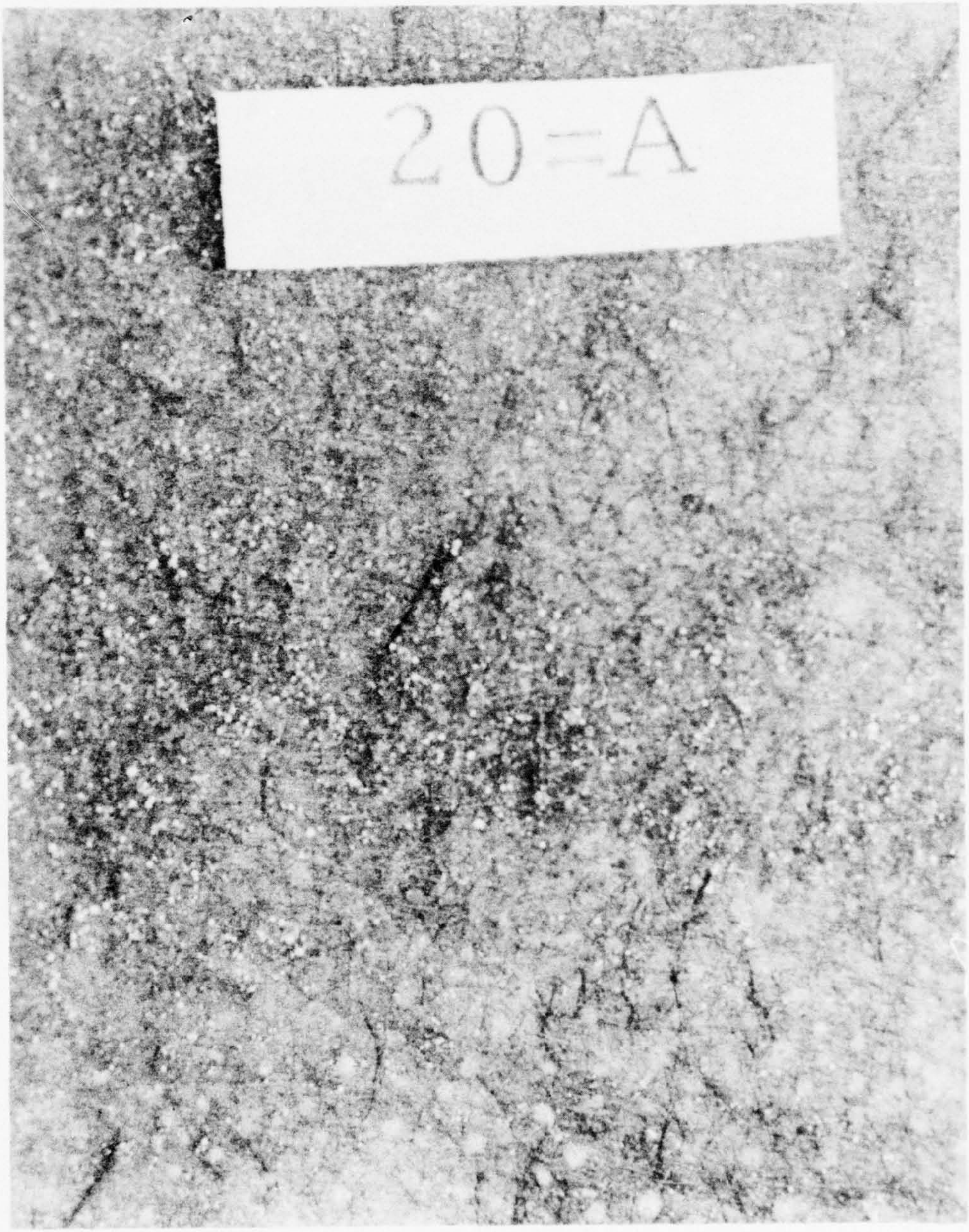


Figure A-7. Test specimens cut from tube section 020.



(a) ORIGINAL TUBE BORE SURFACE (X10)

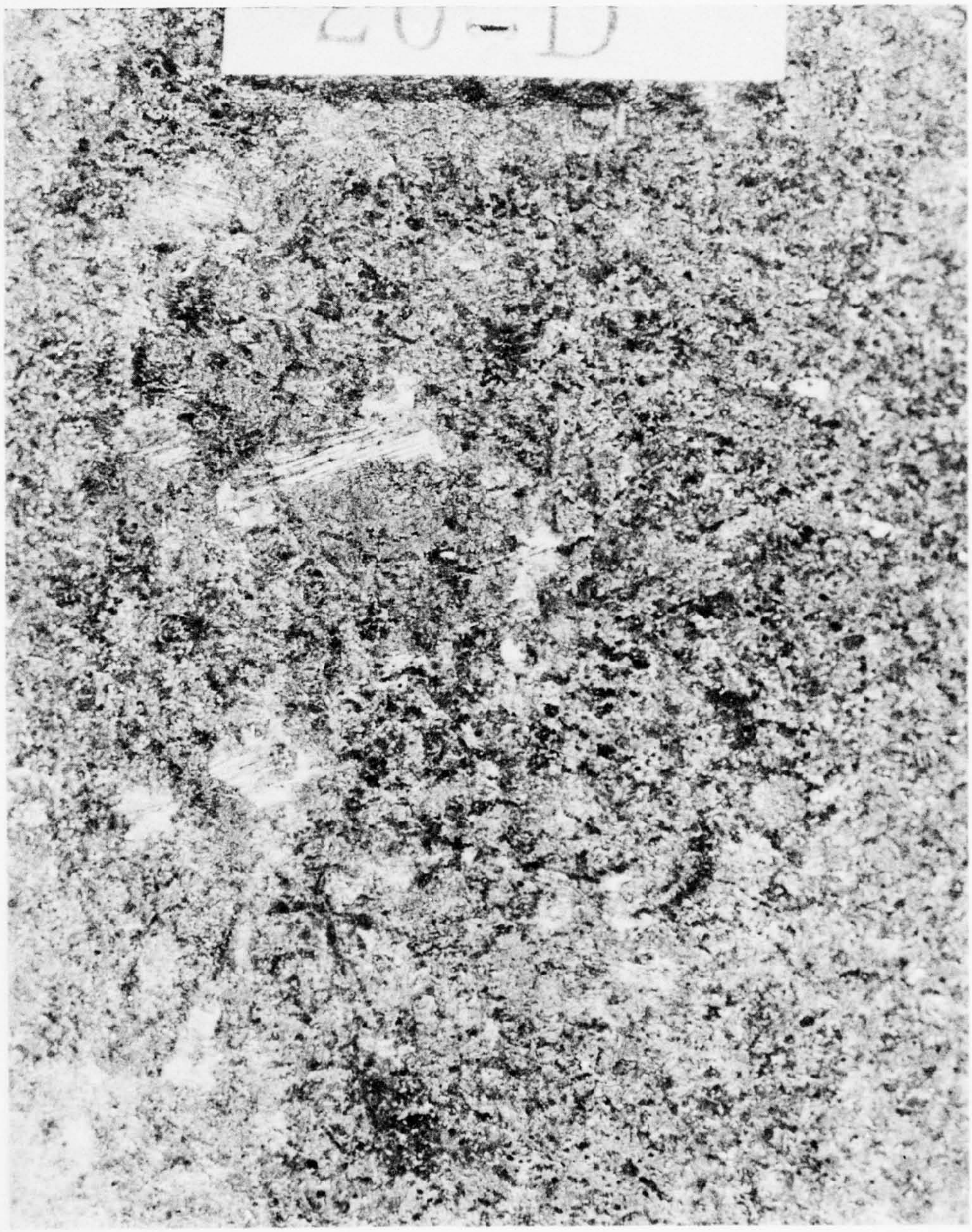
Figure A-7. (Continued).

(b) BORE SURFACE AFTER APPLICATION OF HEAT TEST CONDITION (X10)

Figure A-7. (Continued).

(c) BORE SURFACE AFTER APPLICATION OF HEAT PLUS GRIT TEST CONDITION (X10)

Figure A-7. (Continued).



(d) BORE SURFACE AFTER APPLICATION OF HIGH HEAT TEST CONDITION (X10)

Figure A-7. (Concluded).

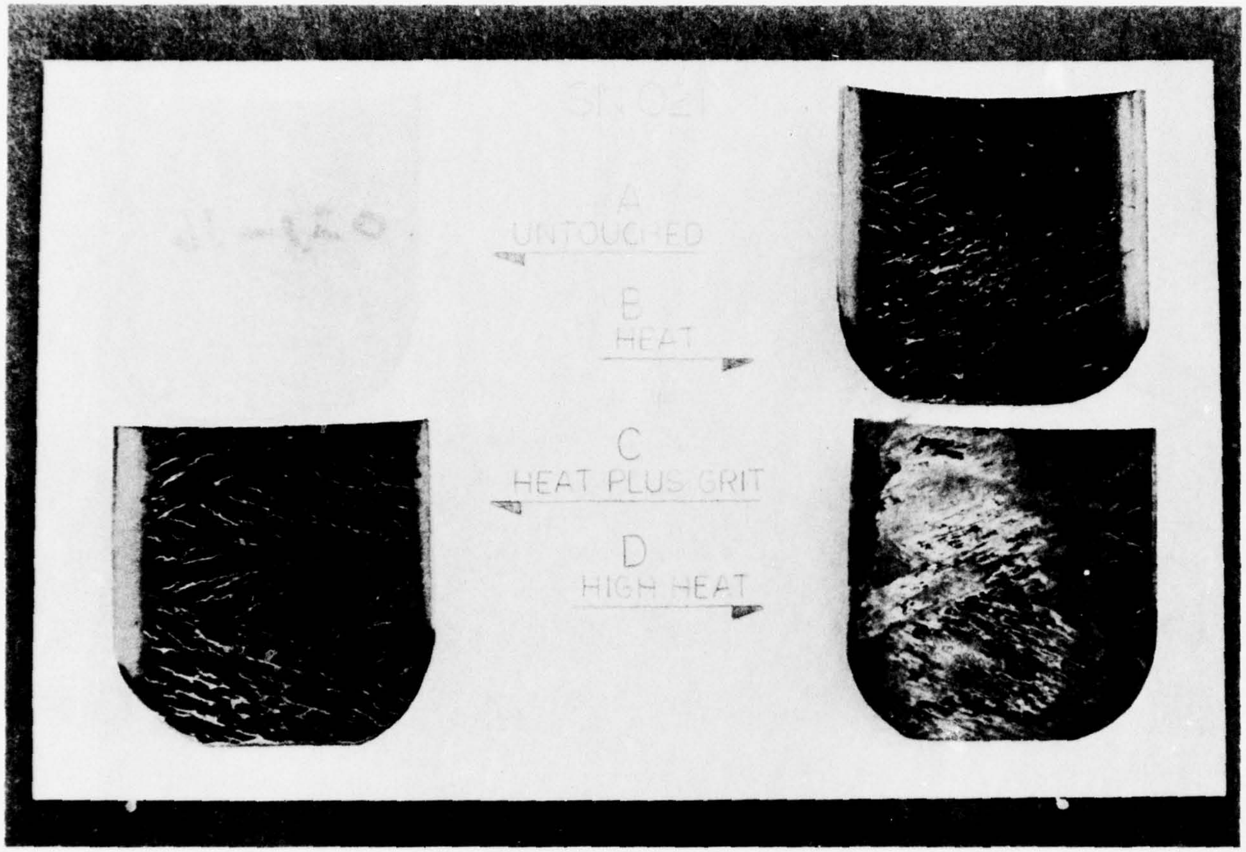
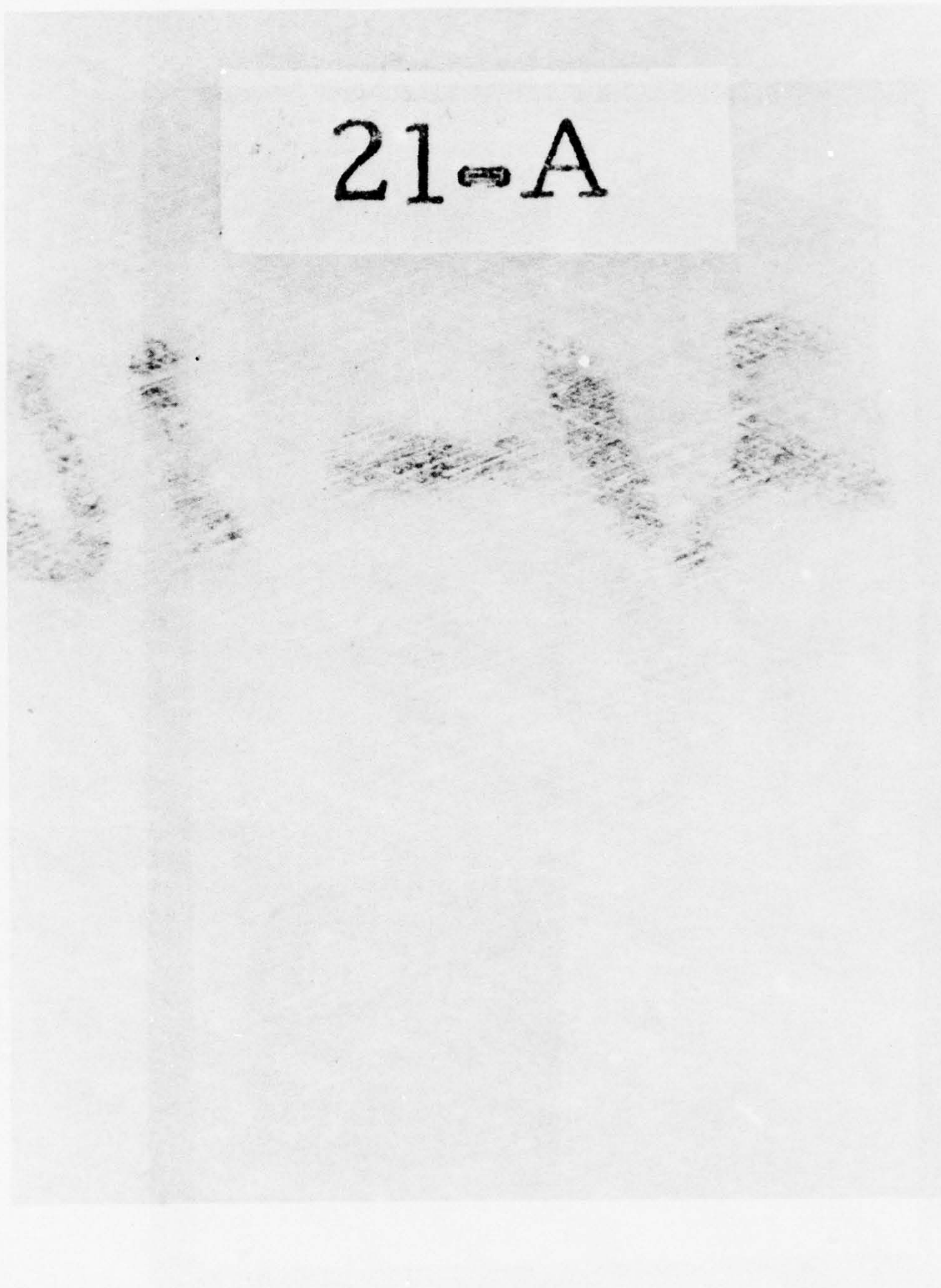
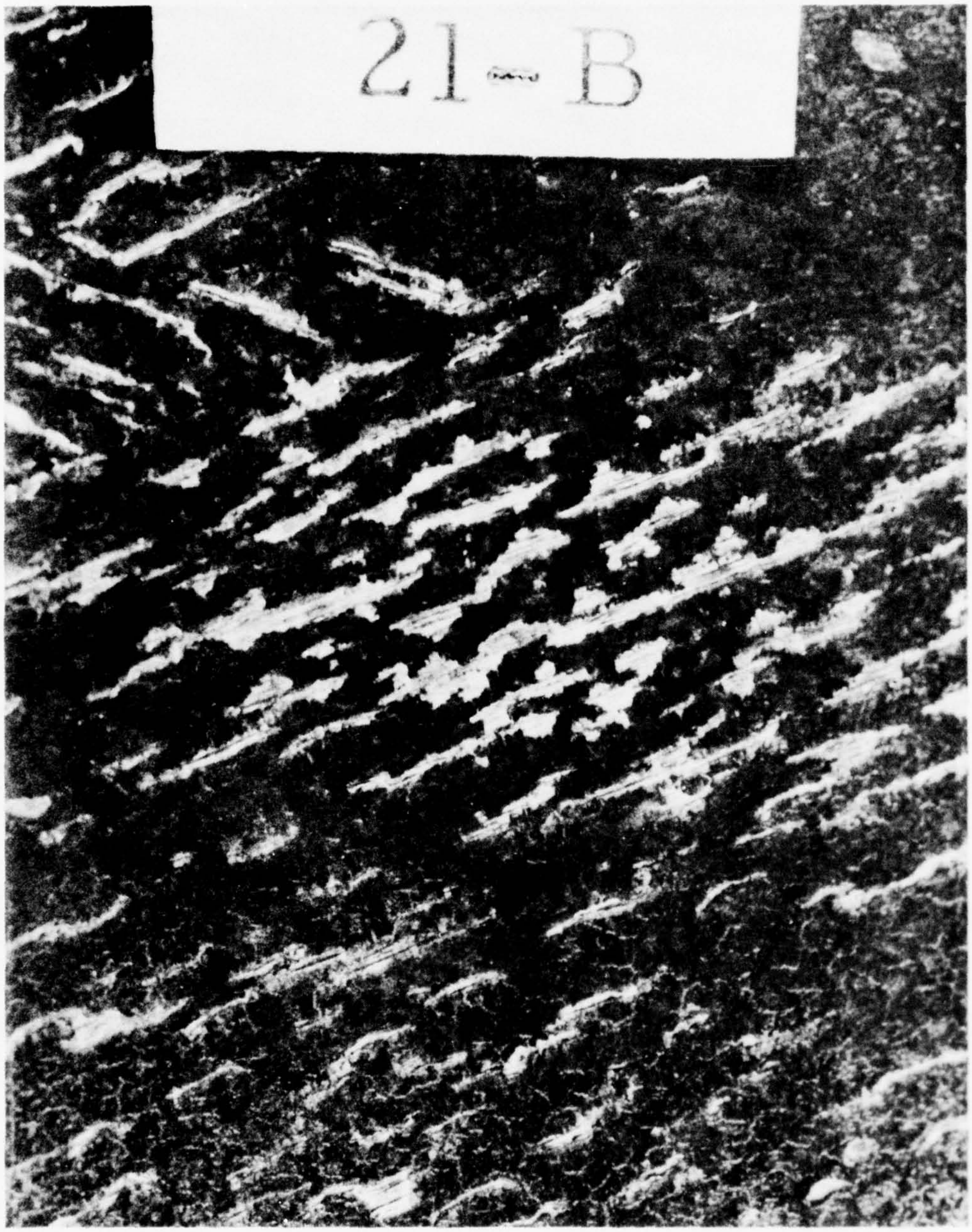


Figure A-8. Test specimens cut from tube section 021.



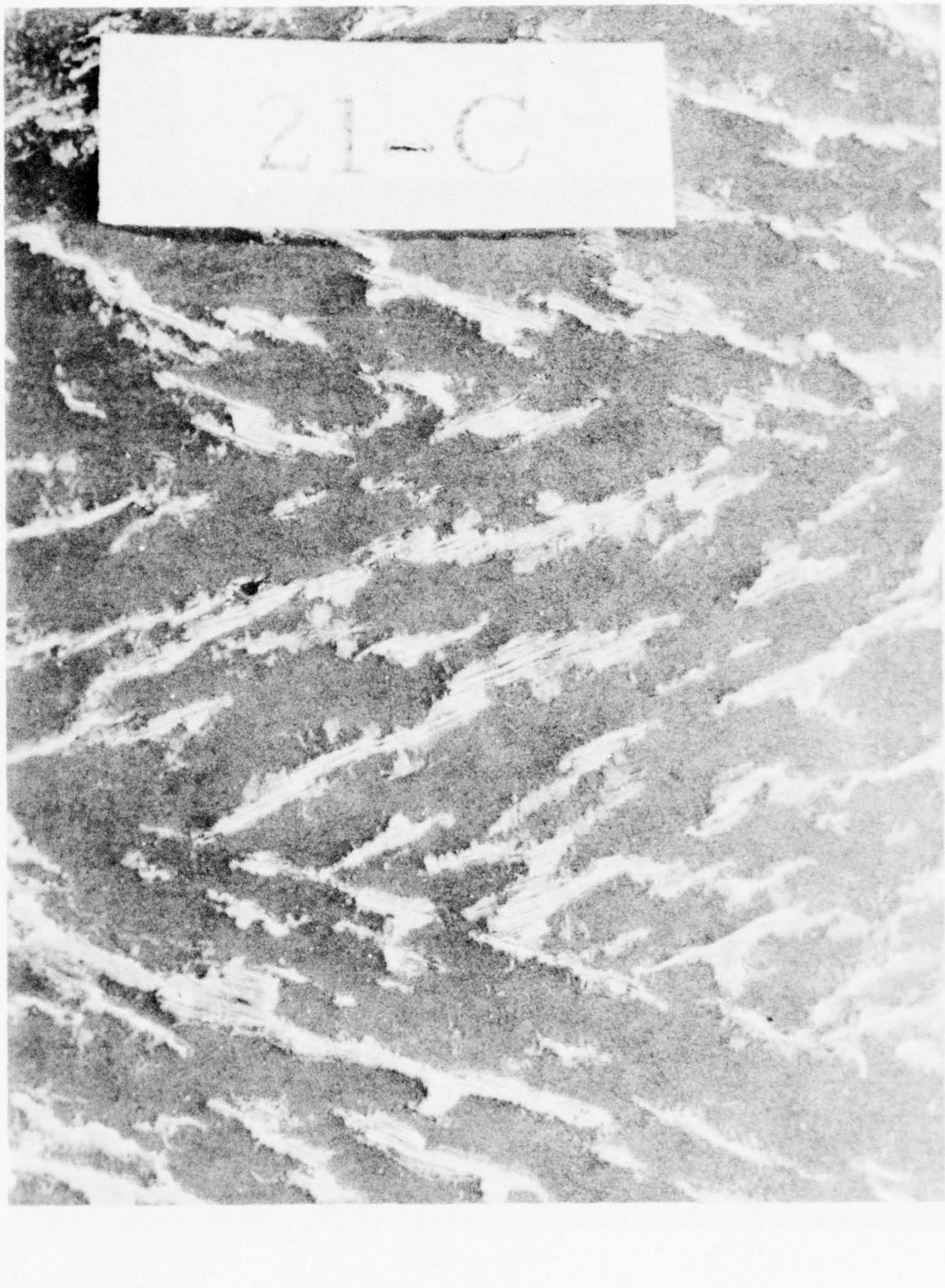
(a) ORIGINAL TUBE BORE SURFACE (X10)

Figure A-8. (Continued).



(b) BORE SURFACE AFTER APPLICATION OF HEAT TEST CONDITIONS (X10)

Figure A-8. (Continued).



(c) BORE SURFACE AFTER APPLICATION OF HEAT PLUS GRIT TEST CONDITION (X10)

Figure A-8. (Continued).

(d) BORE SURFACE AFTER APPLICATION OF HIGH HEAT TEST CONDITION (X10)

Figure A-8. (Concluded).

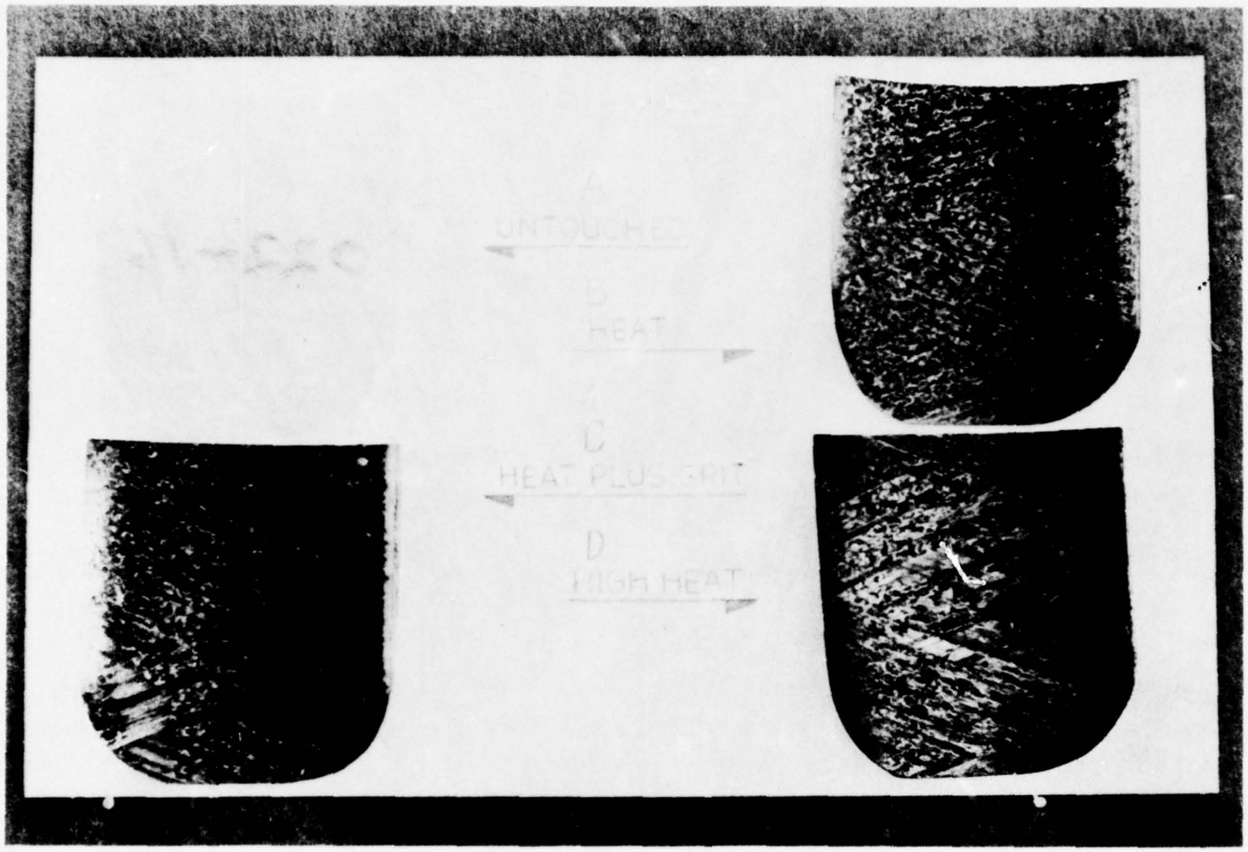
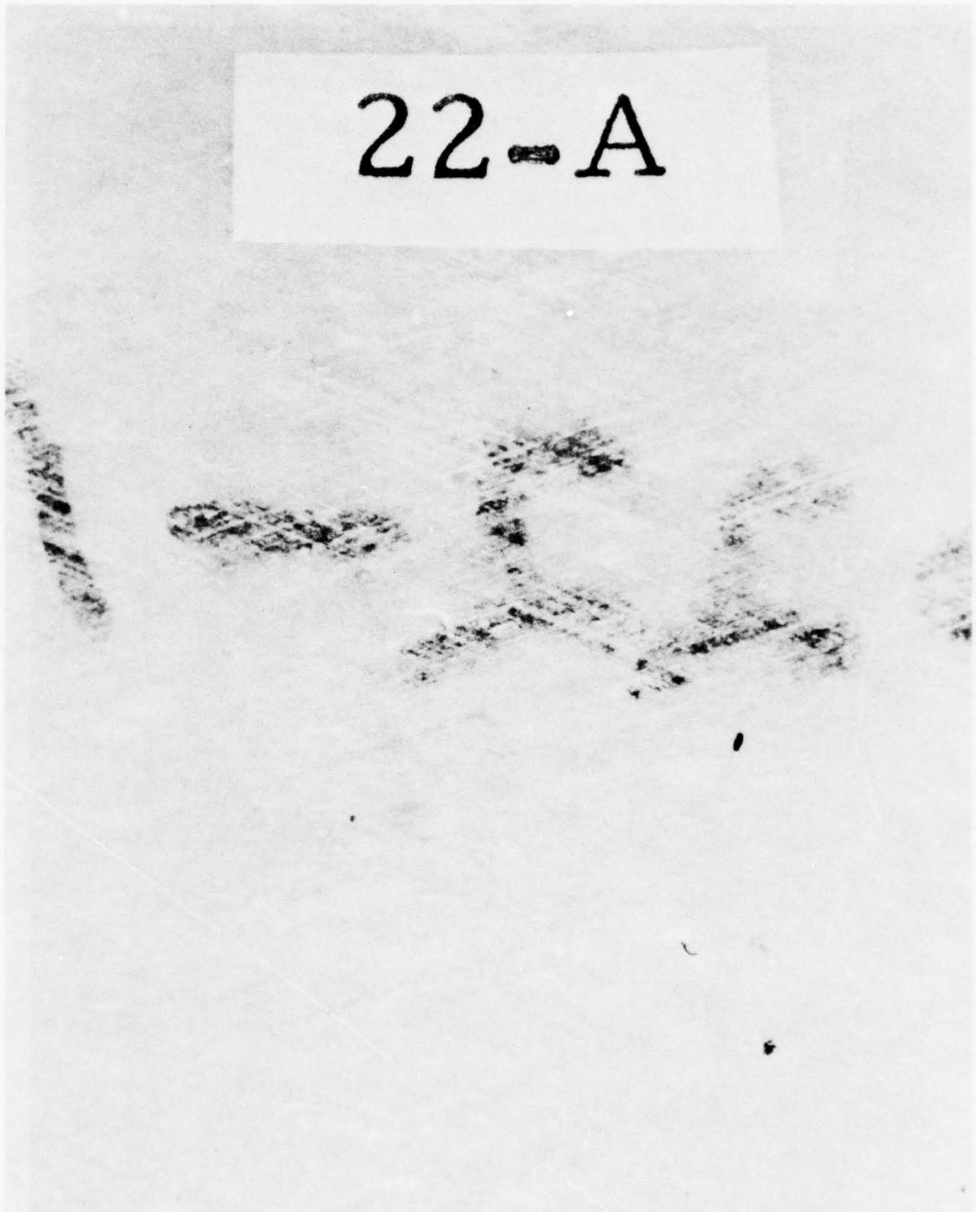
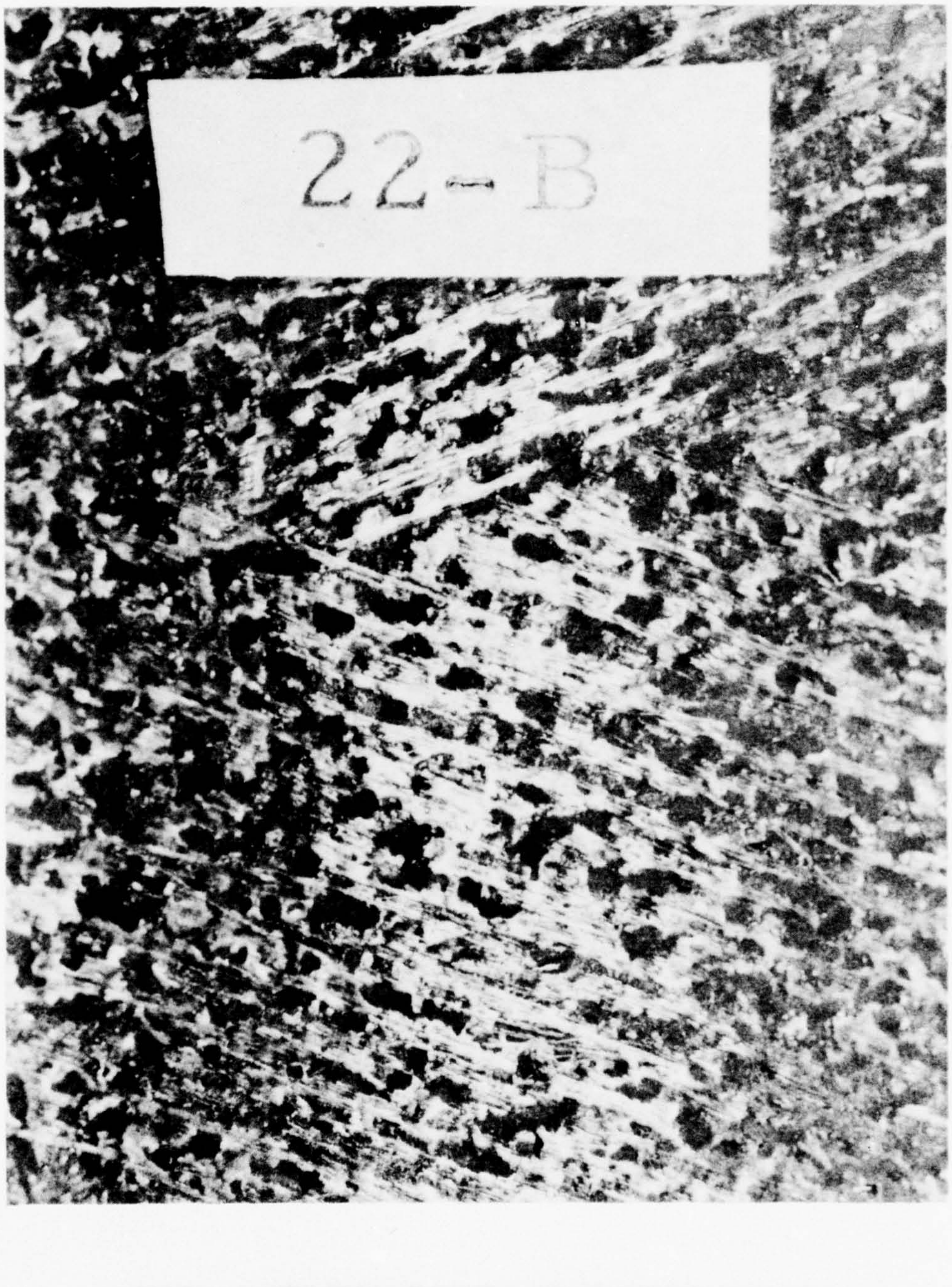


Figure A-9. Test specimens cut from tube section 022.



(a) ORIGINAL TUBE BORE SURFACE (X10)

Figure A-9. (Continued).



(b) BORE SURFACE AFTER APPLICATION OF HEAT TEST CONDITION (X10)

Figure A-9. (Continued).

(c) BORE SURFACE AFTER APPLICATION OF HEAT PLUS GRIT TEST CONDITION (X10)

Figure A-9. (Continued).

(d) BORE SURFACE AFTER APPLICATION OF HIGH HEAT TEST CONDITION (X10)

Figure A-9. (Concluded).

Appendix B.

REUSABILITY OF FILAMENT-WOUND LAUNCH TUBES
(BRUNSWICK CONTRACT)

REPORT DAAH01-76-C-0483

REUSABILITY OF FILAMENT WOUND LAUNCH TUBES

William E. Dick
Defense Division
Brunswick Corporation
4300 Industrial Avenue
Lincoln, Nebraska 68504

23 July 1976

Final Report for Period 14 January 1976-14 July 1976

Distribution in accordance with AR 70-31, C3

Prepared For

U.S. Army Missile Command
Redstone Arsenal, Alabama 35809

Chief, DCASO, Kansas City
Room 201, Noland Plaza Building
ADPP: S2603A
3675 South Noland Road
Independence, Missouri 64055

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4. TITLE (and Subtitle) Reusability of Filament Wound Launch Tubes		5. TYPE OF REPORT & PERIOD COVERED Final Report for Contract Period:14 Jan.1976-14 July 1976
		6. PERFORMING ORG. REPORT NUMBER
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11. CONTROLLING OFFICE NAME AND ADDRESS U. S. Army Missile Command Redstone Arsenal, Alabama 35809		12. REPORT DATE 23 July 1976
		13. NUMBER OF PAGES 32
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19. KEY WORDS (Continue on reverse side if necessary and identify by block number) Launch Tubes, composites, launch tube thermal environment, reusable launch tubes.		
20. ABSTRACT (Continue on reverse side if necessary and identify by block number) An analysis of the launch tube environment produced by an aluminized rocket propellant was performed. Several matrix and liner materials were evaluated for their suitability for repeated use in launch tubes. Tubular specimens were fabricated and tested using a torch test fixture and a grit blast procedure. Twelve of the most promising systems were selected for shipment to the Army Missile Command for further evaluation.		

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Contract No. DAAH01-76-C-0483
Reusability of Filament Wound Launch Tubes
Period: January 14, 1976-July 14, 1976

INTRODUCTION

The work covered in this report was performed under contract DAAH01-76-C-0483 and is for the contract period of January 14, 1976 through July 14, 1976.

Although high strength fiber/resin composites have been used extensively in rocket launch tubes by the Army and others, in these applications the launch tube has been a one shot, expendable item. An obvious improvement in the cost effectiveness of some launch tube applications could be achieved if the launch tubes could be reused.

The purpose of this study was to define several alternative material/design systems for filament wound launch tubes which have the potential to withstand repeated exposure to an environment caused by the aluminized propellant and to supply the Army Missile Command with tubular specimens of the most promising systems for further testing and evaluation.

DISCUSSION

ROCKET EXHAUST ENVIRONMENT

The inside of the launch tube is subjected to an environment that includes several potential forms of attack. Primarily, ablation of the launch tube surface is a result of thermal damage and mechanical abrasion. The thermal damage is a function of gas temperature, velocity and time of exposure. Mechanical abrasion is due to the particulate matter present in the combustion products of aluminized rocket propellant.

The relative significance and interaction of these two effects is difficult to predict analytically. However, in order to obtain an order of magnitude idea of the thermal environment in the launch tube, the following analysis based on available information was performed.

LAUNCH TUBE THERMAL ANALYSIS

In order to evaluate the performance of various launch tubes in combination with different rockets, it is necessary to determine approximate flame velocities and tube surface temperatures. Some assumptions were necessary to obtain these values which, in addition to uncertainties associated with empirical equations, limit the accuracy of the results. However, the analysis does give good comparative data and indicates what effects a variable has on tube performance.

A step-by-step analysis is performed for rocket #3 (per Technical Requirement No. 6005) in a 3-inch diameter launch tube. Results from a similar analysis are also given for rockets #1 and #2 (see Table I for characteristics of rockets #1 thru #3).

For rocket #3:

P_o = 6150 psi
k = 1.18
T_o = 6310 °R
D_1 = 1.71 in. (throat)
D_2 = 2.50 in. (nozzle)
D_3 = 3.00 in. (tube)

$g_c = 32.2 \dfrac{ft\text{-}lb_m}{lb_f\ sec^2}$

$R = 64.4 \dfrac{ft\text{-}lb_f}{lb_m\ °R}$

Burntime = .008 sec.
P_3 = 500 psi (assumed)

Analysis of the exhaust gases of a typical polyurethane fuel containing aluminum yields the following bulk properties:

C_p = 2.0 Btu/lbm°F
Pr = .69
ρ = .007 lb_m/ft^3
μ = 2.3 x 10^{-5} lb_m/ft-sec
R = 64.4 $ft\text{-}lb_f/lb_m$°R

For an isentropic flow process, the nozzle exit velocity can be found:

$$M_2 = M_1\ A_1/A_2 \sqrt{\left(\frac{1 + \frac{k-1}{2}\ M_2^2}{1 + \frac{k-1}{2}\ M_1^2}\right)^{\left(\frac{k+1}{k-1}\right)}} = 2.1 \qquad (1)$$

The acoustic velocity at the nozzle was found:

$$V_a = \sqrt{g_c kRT} = 3330 \text{ ft/sec} \qquad (2)$$

which results in an exit velocity of

$$V_2 = 7000 \text{ ft/sec}$$

The pressure at the nozzle was:

$$P_2 = P_o \left(1 - V_2^2\ \frac{k-1}{2gk}\ \frac{1}{RTo}\right)^{\left(\frac{k}{k-1}\right)} = 685 \qquad (3)$$

The existence of an additional pressure drop from the nozzle (P_2) to the tube (P_3) resulted in the assumption of a 500 psi tube pressure.

To find the gas temperature at the nozzle:

$$T_2 = T_o \left(\frac{P_2}{P_o}\right)^{\left(\frac{k-1}{k}\right)} = 4515 \text{ °R} \qquad (4)$$

Equations (2), (3) and (4) were solved successively to close in on the given solution.

To obtain the gas velocity in the tube, the principle of conservation of mass was applied.

$$V_3 = \frac{\rho_2}{\rho_3} \frac{A_2}{A_3} V_2 = 6300 \text{ ft/sec}$$

To find the gas temperature in the tube

$$T_3 = T_o \left(\frac{P_3}{P_o}\right)^{\left(\frac{k-1}{k}\right)} = 4300 \text{ °R}$$

The adiabatic wall temperature, which is the true driving potential, is not significantly lower than the temperature (T_3) calculated.

The following empirical equation was used to find the convection heat transfer coefficient.

$$h = .023 \ R_e^{-.2} \ Pr^{-2/3} \ C_p \ \rho V = 340 \ B_{tu}/\text{hr-ft °F}$$

Radiation heat transfer was analyzed and found to be negligible.

Using the calculated values for T_3 and h and assuming appropriate material properties for the launch tube, the approximate tube wall temperature after .008 seconds was determined to be 550°F.

A summary of the results of the analysis of the three rocket systems listed in Technical Requirement No. 6005 is given in Table I.

TABLE I

GIVEN:	ROCKET #1	ROCKET #2	ROCKET #3
P_o	2500	2200	6150 psi
k	1.21	1.20	1.18
T_o	5740	5350	6310 °R
D_1	1.8	1.96	1.71 in.
D_2	5.8	3.11	2.5 in.
D_3	8	14	3 in.
Burn Time	.25	.30	.008 sec.
g	32.2	32.2	32.2 ft-lb_m/lb_f sec^2
R	64.4	64.4	64.4 ft-lb_f/lb_m °R
Assume:			
P_3	20	50	500 psi
Results:			
V_2	8600	6700	7000 ft/sec
V_3	7400	1000	6300 ft/sec
h	640	115	340 Btu/hr-ft °F
T_3	2400	2850	4300 °R
T_{wall}	1550	1050	550°F

SUBSCRIPTS

o - chamber
1 - throat
2 - nozzle
3 - tube

From the results of the thermal analysis it would appear that thermal damage should be less significant for high impulse, short burn time rocket systems than for the larger, slower systems. For most resin systems considered in this study, brief exposure to 500-600°F should not result in any permanent damage. The Epon 828/NMA resin system, for example, is sometimes post cured at near 500°F to increase its heat distorsion temperature. Examination of launch tubes which have been subjected to an exhaust environment similar to rocket No. 3 indicates no obvious evidence of thermal damage (i.e., charring or discoloration). Laboratory tests were run by Brunswick on tubes of similar construction, and the surface condition of the fired tubes could only be duplicated by alumina grit blasting. Torch tests on these tubes and others, reported on in more detail later in this report, resulted in discoloration, blistering and, finally, charring of the resin, none of which was apparent on the fired launch tubes. Photographs of a fired launch tube and tube sections subjected to laboratory tests are included as an appendix to this report.

It is possible that heat softening may have contributed to the erosion in the fired tubes, and that some amount of surface sublimation may be taking place, and it is likely that in rocket systems similar to no's. 1 and 2 in the Technical Requirements the thermal effects would be significant. However, these analytical and experimental results do raise some questions about the validity of a pure thermal test for the evaluation of launch tube materials in some applications.

MATERIAL SYSTEM SELECTION

As part of the original program plan, a matrix of potential materials for winding and liners was generated. This matrix is given as Table II. As the program progressed, the original matrix was continuously revised and expanded. Two general approaches were considered. The first and preferred approach was to define a winding resin which would result in a composite which met the program objectives. As an alternative approach, a liner material to shield the overwrap from the rocket exhaust environment was considered.

The criteria for selecting resin systems for winding was based on the consideration of heat distortion, flammability and toughness (abrasion resistance) as well as cost and processability.

From preliminary results obtained at MICOM on 2.75 inch diameter launch tubes, it appeared that a thin (approx. .020") gel coat liner offered a considerable amount of protection to the tube surface, and liner material evaluation was a significant part of this study. Included in the criteria for liner material selection was: heat distortion temperature, flammability, abrasion resistance, thermal conductivity and auto-lubrication. Increased thermal conductivity of the liner material would increase the thermal capacity, and thus reduce the surface temperature of the tube, while auto-lubrication (e.g., graphite) may reduce abrasion.

A summary of the matrix and liner materials evaluated in this study is given in Table III. The alphabetic code was assigned to facilitate tabulation of test data.

TABLE II

REUSABLE LAUNCH TUBE MATERIAL MATRIX (1) - CC 10211

SYSTEM NO.	MATRIX MATERIAL	LINER CONFIG./MAT'L.	RESISTANT TO: HEAT	RESISTANT TO: WEAR	COMMENTS
1	LRF-092	None			Baseline (250°F)
2	LRF-216	None			Low HDT (150°F)
3	APCO 2447	None	X		High HDT (350°F)
4	Kerimid	None	X		High Temp. Resins
5	Triazine A	None	X		High Temp. Resins
6	XYLOC (235C)	None	X		High Temp. Resins
7	LRF-092	LRF-002/Cabosil			Liner Effects
8	LRF-092	LRF-002/Asbestos			Liner Effects
9	LRF-092	LRF-002/Graphite Cloth	X	X	Graphite for Therm. Cond. & Wear
10	LRF-092	APCO 2447/Cabosil	X		Novolac Epoxy Liner
11	LRF-092	APCO 2447/Asbestos	X		Novolac Epoxy Liner
12	LRF-092	APCO 2447/Graphite Cloth	X	X	Novolac Epoxy Liner
13	LRF-092	LRF-092/Barrium-MICA		X	Already wound at Amerac
14	LRF-092	$AlPO_4$	X		High Temp. (1200°F)
15	LRF-092	$Al(OH)_3$ H_2O/Resin (?)	X		Emits H_2O When Heated
16	LRF-092	Epoxy/Urethane		X	Tough
17	LRF-092	Silicone Elastomer (RTV)	X	X	Tough & High Temp.
18	APCO 2447	"Coors Ceramic Particles"	X	X	Suggested by T.T. Chiao
19	LRF-092	Longo Mat/Resin (?)		X	Fiber Direction
20	LRF-092	Veil Mat/Resin (?)			Liner Effects

(1) This list will be periodically updated as new information is received. Tubes are to be shipped from 12 systems.

TABLE III
SUMMARY OF MATERIAL SYSTEMS EVALUATED

MATERIAL CODE	MATERIAL DESCRIPTION
Matrix Materials	
A	Epon 828/Nadic Methyl Anhydride/Benzyldimethyl Amine
B	Epon 828/Nadic Methyl Anhydride/ATC-3
C	Apco 2447 (Novolac Epoxy)
D	Dow 7575.02 (CTBN Modified Epoxy)
E	Epon 828/NMA (Tube Provided by MICOM)
F	Xyloc 235-C
Liner Materials	
G	Epon 828/Aliphatic Amine/Cabosil
H	Epon 828/Aliphatic Amine/Asbestos Cloth
I	Epon 828/Aliphatic Amine/Chopped Graphite
J	Resin C/Cabosil
K	Resin C/Asbestos Cloth
L	Resin C/Chopped Graphite
M	Resin A/Graphite Cloth
N	Resin C/Graphite Cloth
O	Polane (Polyurethane)
P	Resin A/Cabosil
Q	Resin D/Cabosil
R	Barium-Mica (Supplied by MICOM)

TUBE PROCESSING

Tube specimens in this study were fabricated to detailed processing documents. The tube overwraps were all wound with 20 end, Type 801 E-glass at ± 70° wind angle and 14 rovings per inch. Four layers were applied to an approximate thickness of .040 inch. An attempt was made to hold the liner thickness to around .020 inch, but the actual thickness varied depending on the nature of the liner material. The more viscous materials tended to result in thicker liners. In all cases an uncured gel coat was applied to the mandrel surface prior to winding to eliminate dry fibers from the inner tube surface and to improve the bond between the liner and the overwrap for the lined tubes.

EXPERIMENTAL EVALUATION

Most of the test work was carried out using the same 3.110 inch diameter tubes which were eventually shipped to MICOM for further evaluation. A few materials were subjected to preliminary evaluation using flat laminates and NOL rings, but the ones selected for shipment to MICOM were also evaluated as tubular specimens. A summary of tubes shipped to MICOM is given in Table IV. Several other resin systems were considered, but because of various processing impracticalities and cost disadvantages, they were not selected for experimental evaluation.

Evaluation of each material system was performed using the test fixture shown in Figure 1. The fixture was designed to pass the specimen through a controlled thermal or abrasive environment produced by an oxyacetylene torch or a grit blast nozzle. In Figure 2 is a photograph of the test fixture in operation. The grit used in this test was 100 mesh alumina. The test specimen can be passed through the environment at varying speeds by means of a DC motor and variable power supply. After two combined torch and grit blast tests using the fixture, it was decided that the abrasive environment was too severe for the fixture and all further grit blast tests were run using a hand held gun and a fixed period of exposure.

Hardness of the specimens was measured using a hand held Barcol Impressor, Model 934-1. Ablation was measured by measuring the specimen thickness before and after testing. Some difficulty was encountered in measuring specimen thickness. Because irregularities in the outside surface were occasionally of the same order of magnitude as the ablation being measured, accurate measurements were not always possible.

RESULTS

A summary of the results of the torch tests and grit blast tests is presented in Table V. For every specimen the amount of ablation (thickness reduction) was measured, and a Barcol Hardness test was performed before and after each torch test. In addition, pictures were taken of each of the specimens and are included in Appendix A.

TABLE IV
SUMMARY OF LAUNCH TUBE SPECIMENS SHIPPED TO MICOM

S/N	MATRIX	LINER MATERIAL
002	Epon 828 Ciba 906 Hardener (NMA) ATC-3 Accelerator	None
003	Apco 2447	None
006	Epon 828 Ciba 906 Hardener (NMA) BDMA	Chopped Graphite Fiber Epon 828 Aliphatic Amine
012	Dow XD-7818 Dow XD-7575.02 Epoxide 8 Tonox 6040	None
013	Epon 828 Ciba 906 Hardener (NMA) BDMA	Polane (Urethane)
014	Epon 828 Ciba 906 Hardener (NMA) BDMA	Epon 828 Ciba 906 Hardener (NMA) BDMA Filler (Cabosil)
015 (Baseline)	Epon 828 Ciba 906 Hardener (NMA) BDMA	None
017	Epon 828 Ciba 906 Hardener (NMA) BDMA	Dow XD-7575.02 Dow XD-7818 Epoxide 8 Tonox 6040
019	Xyloc 235 (Proprietary High Temperature Resin)	None
020	Epon 828 Ciba 906 Hardener (NMA) BDMA	Apco 2447 Chopped Graphite Roving
021	Epon 828 Ciba 906 Hardener (NMA) BDMA	Epon 828 Ciba 906 Hardener (NMA) ATC-3 Accelerator Cabosil
022	Epon 828 Ciba 906 Hardener (NMA) BDMA	Apco 2447 Cabosil

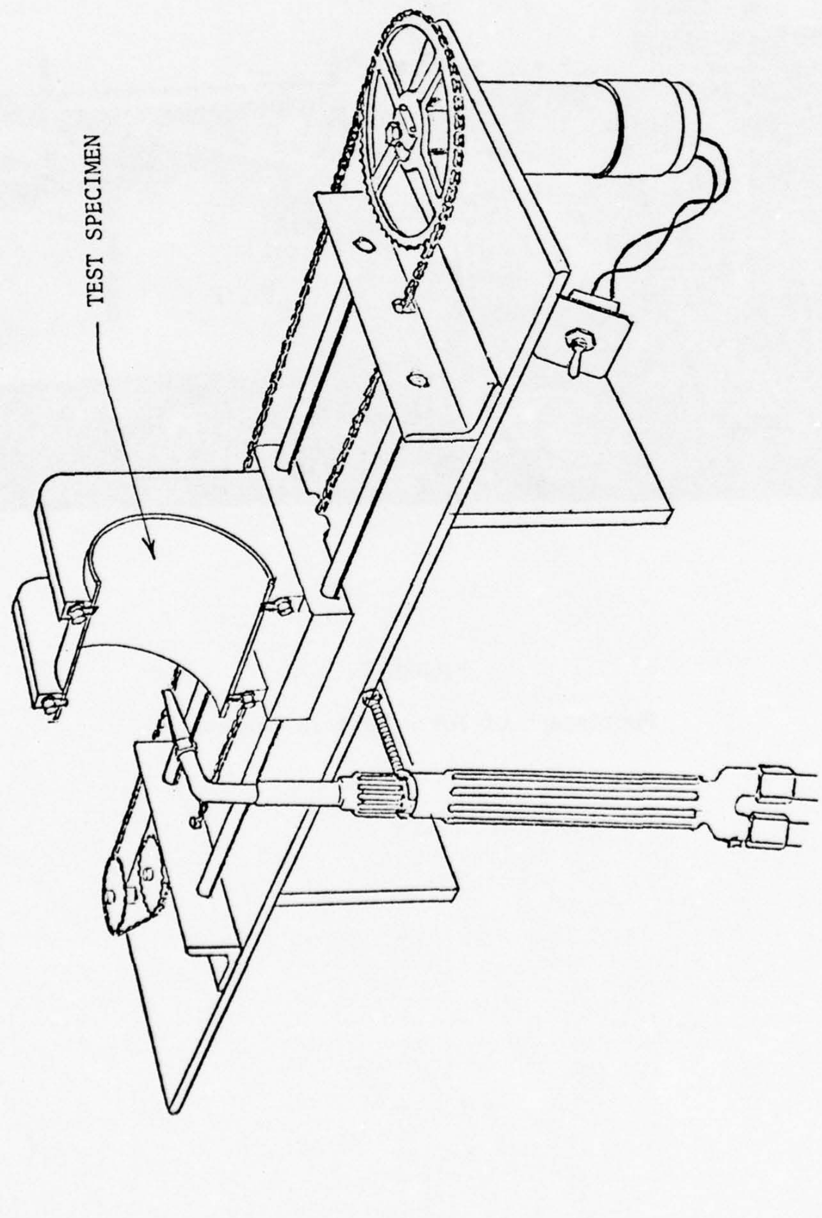

FIGURE 1
SKETCH OF TEST FIXTURE WITH TORCH MOUNTED

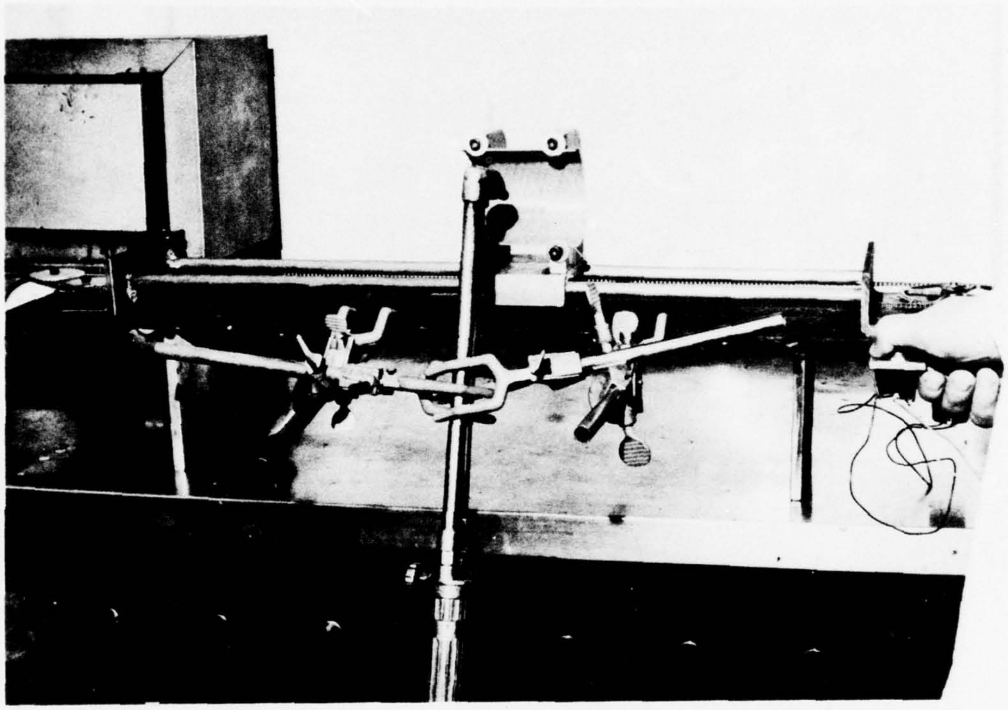

FIGURE 2

Photograph of Torch Test in Process

TABLE V(a) - TEST RESULTS

TUBE S/N	MATRIX	LINER	TEST TYPE	ABLATION (THICKNESS REDUCTION)	BARCOL HARDNESS BEFORE TEST	BARCOL HARDNESS AFTER TEST	OBSERVATIONS
001	A	-	Torch	.001"	73	64	Darkening, slight blistering
001	A	-	Torch	.000"	74	66	
001	A	-	Torch	.000"	73	66	
001	A	-	Grit	.006"	--	--	Resin ablated into first fiber layer
002	B	-	Torch	.001"	70	59	Darkening, slight blistering
002	B	-	Torch	.001"	65	60	
003	C	-	Torch	.001"	72	68	Slight blistering of surface
003	C	-	Torch	.001"	72	68	
003	C	-	Grit	.008"	--	--	Surface resin and part of 1st fiber layer ablated
004	A	G	Torch	(.005")	62	52	Slight darkening - no blisters
004	A	G	Torch & Grit	.007"	58	65	Liner and some fiber ablated
005	A	H	Torch	.003"	55	34	Darkening, slight ablation
005	A	H	Torch & Grit	.002"	55	42	Surface ablated - cloth fibers exposed
006	A	I	Torch	.000"	63	59	Slight darkening
006	A	I	Grit	.004"	--	--	Dulled surface, no fibers exposed
007	A	J	Torch	(.001")	69	70	Considerable darkening of surface, no blisters
007	A	J	Torch	(.001")	70	66	
007	A	J	Grit	.001"	--	--	Dull surface, no exposed fibers
008	A	K	Torch	.000"	57	57	Darkening and pitting of surface
008	A	K	Grit	.008"	--	--	Surface ablated - cloth fibers exposed

TABLE V(b) - TEST RESULTS

TUBE S/N	MATRIX	LINER	TEST TYPE	ABLATION (THICKNESS REDUCTION)	BARCOL HARDNESS BEFORE TEST	BARCOL HARDNESS AFTER TEST	OBSERVATIONS
009	A	L	Torch	.001"	70	66	Considerable darkening of surface, no blisters.
009	A	L	Grit	.002"	--	--	Dull surface, no exposed fibers.
010	A	M	Torch	.000"	64	62	Some damage where cloth came near surface.
010	A	M	Grit	.005"	--	--	Surface ablated to cloth.
011	A	N	Torch	.002"	68	69	Surface cracks & blisters corresponding to weave of cloth.
011	A	N	Torch	(.001")	69	60	Surface cracks & blisters corresponding to weave of cloth.
011	A	N	Grit	.013"	--	--	Resin ablated into the weave of the cloth.
012	D	-	Torch	(.001")	42	35	Surface blistering.
012	D	-	Grit	.010"	--	--	Ablation into 2nd ply of fibers.
013	A	O	Torch	.003"	58	64	Surface dull - possible charring.
013	A	O	Grit	.000"	--	--	Dulled surface.
014	A	P	Torch	.000"	53	52	Surface darkened.
014	A	P	Grit	.001"	--	--	Dulling of surface.
017	A	Q	Torch	.000"	53	52	
017	A	Q	Grit	.000"	--	--	
018	E	R	Torch	.000"	68	70	Slight surface darkening.
018	E	R	Grit	.007"	--	--	Liner ablated to 1st fiber ply.
019	F	-	Torch	.002"	50	42	Blisters formed under 1st fiber ply.
019	F	-	Grit	.004"	--	--	Ablation into first fiber ply.

The baseline tube as defined by MICOM was Type 801, E-glass with Shell Chemical Company's Epon 828. The accelerator/hardener system used with 828 for the baseline tube was methylnadic anhydride/benzyldimethyl-amine. To calibrate the effects of the torch test, two other "baseline" resin systems were evaluated - one with a higher heat distortion temperature (Apco 2447 Novolac Epoxy) and one with a lower heat distortion temperature (Epon 828 and methylnadic anhydride/ATC-3). The results of torch tests on these three systems without liners are given below.

	H.D.T.	ABLATION (REDUCTION IN THICKNESS)	HARDNESS BEFORE	HARDNESS AFTER
(2) Epon 828/ATC-3/NMA	150°F.	.001	67.5	59.5
(3) Epon 828/BDMA/NMA	250°F.	.000	73.3	65.2
(2) Apco 2447	350°F.	.001	72.0	68.0

All tests were performed with the nozzle 2" from the specimen and the specimen moving through the flame at 1.3 feet/second. The numbers in parenthesese indicate the number of specimens tested at this condition. There was very little scatter of these data (see Table IV). Although the results do not show ablation to be significant for any of the resin systems under these test conditions, there is an indication of a reduction in surface hardness. As might be expected, the higher heat distortion temperature resin system showed the smallest decrease in hardness.

MATRIX MATERIAL EVALUATION

As noted in Table II, several resin systems were considered for evaluation as a matrix material. The final selection of four (not including the baseline resin system) was based on a preliminary screening evaluation which considered processability and cost as well as performance potential. A brief discussion of those systems eliminated from consideration under this program and the reasons for their elimination follows.

Triazine A - Triazine is a high temperature resin system made by Mobay Chemical Co. Several resin castings and NOL rings were fabricated with this material but because of excessively high cure shrinkage and processing difficulties, it was deemed unsuitable for filament winding.

Polyimide - Polyimides show some amount of future promise for use in filament winding. They have the inherent disadvantages of high cost and a vacuum bag cure requirement. However, Brunswick has an active in-house program underway to investigate polyimides for filament winding, and it is possible that processing techniques may be developed which will make polyimides more practical for high volume filament wound parts.

Aluminum Phosphate - $AlPO_4$ is an inorganic material for which Brunswick has developed a process for use in high temperature, glass reinforced radomes. It was considered for launch tubes because of its high temperature resistance (approx. 1200°F), but because of its relatively complicated processing requirements and low abrasion resistance, it was eliminated as a viable candidate.

Of the four resin systems chosen for further evaluation as a matrix material, two were high temperature systems and one was an abrasion resistant (toughened) epoxy. The fourth was another anhydride cured Epon 828 system included as a comparison with the baseline system.

Apco 2447 Novolac Epoxy - This resin system appears to offer the best potential for high temperature (500°F) filament wound applications. It is a relatively high strength system that is easily adapted to filament winding. Results of the torch test indicated only a slight reduction in hardness after exposure to the flame.

High temperature strength retention test data developed by Brunswick is given below which indicates that at 550°F, there is only a 34% loss in tensile strength.

APCO 2447 NOVOLAC RESIN TENSILE STRENGTH

	ROOM TEMP.	350°F.	400°F.	450°F.	500°F.	550°F.
Stress	47,000 psi	38,000 psi	34,000 psi	33,000 psi	30,500 psi	31,000 psi
Std. Dev.	2,550 psi	2,926 psi	3,304 psi	2,002 psi	2,022 psi	2,371 psi
C.V.	5%	8%	10%	6%	7%	8%

Visual examination of the specimen following the torch test indicated that considerable darkening of the resin had taken place. However, because of the high temperature performance and processability of this resin, further consideration of Novolac epoxies is warranted.

Xyloc 235C - Xyloc is manufactured by Ciba Geigy for high temperature (to at least 400°F) applications. It must be vacuum bag cured and difficulty was encountered in maintaining resin content due to a significant decrease in viscosity at elevated cure temperatures. The specimen did not perform well under grit or torch testing. This may have been due, in part, to the low resin content. Grit blasting resulted in the errosion of the matrix well into the first fiber layer. Torch tests resulted in discoloration, blistering, and a reduction in surface hardness. Improved processing techniques must be defined before this system can be considered for launch tube applications.

Carboxyl Terminated Butadiene Acrylonitrile (CTBN) Modified Epoxy Resin - CTBN modified resin systems are recommended where a toughened fracture resistant matrix is desired. During cure of the epoxy small elastomeric particles precipitate out and act as crack arrestors in the matrix. It was felt that if abrasion were the primary form of attack, then this "toughened" material might be attractive. The effect of grit blasting on the CTBN matrix was surprisingly severe. The composite was eroded through the first ply of fiber (.010 inch). The thermal test results were darkening of the resin and a reduction in hardness.

Epon 828/NMA/ATC-3 - This is a relatively low heat distortion anhydride cured system. Its performance in the tests was similar to the baseline system.

Based on these bench test results, none of the matrix materials evaluated under this program offer any significant improvement over the baseline material. However, it must be emphasized that these bench tests do not duplicate rocket exhaust environments present in actual launch tubes, and a material should not be eliminated because of these test results alone.

LINER MATERIAL EVALUATION

The function of a polymeric liner in a launch tube is not entirely clear. From results obtained at MICOM and Brunswick on actual launch tubes, it appears that a relatively thin layer of resin on the inside of the tube provides considerable protection to the overwrap. In fact, it has been demonstrated that a tube with a liner of a material with a lower heat distortion temperature than the matrix material will perform better than the same tube without the liner. Three mechanisms were considered as potential functions of the liner. From a thermal standpoint, the liner may be providing a higher specific heat surface, thus reducing the surface temperature. The homgeneity of the liner may also make it less sensitive to thermal shock than a composite surface. Protection from abrasion may be provided due to the lower modulus of the liner as compared to the composite. The consideration of these mechanisms dictated the choice of materials evaluated under this portion of the program.

Each liner material will be briefly discussed including the results of testing.

Epon 828/Aliphatic Amine/Cabosil - This is a room temperature cure resin system and is similar to the TETA cured system tested by MICOM. The MICOM test results indicated that this liner suffered no apparent damage when subjected to rocket firing. Under the torch test, there was discoloration, and a reduction in hardness from 62 to 52. The apparent increase in specimen thickness may have been due to the difficulty in obtaining accurate thickness measurements. A combined torch and grit blast test was run on this material which resulted in .007 inch ablation and a net increase in hardness, probably indicating that much of the liner was blown away and the hardness measurement was being effected by the overwrap. This test is obviously more severe than MICOM's rocket firing. The appearance of the ablated surface was similar to the unlined launch tube tested at MICOM.

Epon 828/Aliphatic Amine/Asbestos tape - Asbestos tape has been occasionally used as a shield for composite structures in regions where high temperature rocket exhaust impinges directly on the surface. In most launch tubes the use of asbestos could probably be limited to the aft portion of the tube where thermal exposure is greatest. Exposure of the specimen to the torch test resulted in a small amount of measured ablation (.003 inch) and a significant reduction in surface hardness. A combination torch and grit blast test resulted in considerable ablation, exposing the asbestos fibers. The low cure temperature and relatively low strength of the resin system were probably detrimental under these test conditions.

Epon 828/Aliphatic Amine/Chopped Graphite - The degree to which a surface can absorb heat while minimizing wall temperature is determined by the specific heat and thermal conductivity of the wall material. Most resin systems are characterized by reasonably high specific heats but very low thermal conductivity. High conductivity fillers can be introduced into the resin to increase conductivity. For this study chopped graphite fibers were blended in the resin (8% by weight). In addition to improved conductivity, it was felt that the graphite may offer some surface lubrication in actual launch tubes. Results of the torch test indicated a possible improvement in hardness reduction (63 to 59 compared to 62 to 52 for no graphite). Grit blasting resulted in a dulling of the surface and .004" ablation but the liner was still intact.

Apco 2447/Cabosil - Because of its better high temperature strength, Apco 2447 was considered as a liner material. The torch test, again, resulted in considerable darkening of the surface with little hardness reduction. Two specimens from the same tube were torch tested with differing results, suggesting that the effect of the torch test on Apco 2447 may be somewhat irratic.

Apco 2447/Asbestos Cloth - The addition of asbestos cloth to the Apco 2447 liner appears to be detrimental to the liner's performance. Besides the usual darkening, the surface was badly ablated and marked with small pits. The pitting suggests that the surface may be subjected to thermal shock. These results are consistant with other asbestos cloth tests and, to some extent, with graphite cloth. It appears that a high resin content in the liner is a requirement.

Apco 2447/Chopped Graphite - The results from a chopped graphite filled Apco 2447 liner were similar to previous results using chopped graphite. The torch test resulted in a darkened surface and the grit blast in a dulled surface. There was little, if any, ablation.

Epon 828/Nadic Methyl Anhydride/Benzyldimethyl Amine/graphite cloth - In the original program definition, it was felt that a graphite cloth liner, besides providing the benefits of chopped graphite, would provide some additional reinforcement for the tube. Torch test of the specimen resulted in some localized surface damage where the weave of the cloth neared the surface of the resin. Grit blasting removed the thin layer of resin covering the cloth and exposed the graphite yarn. These results reiterate the need for a high resin content liner.

Apco 2447/Graphite cloth - The results of a Apco 2447/graphite cloth liner were similar to the Epon 828 system discussed above. Irratic hardness data was due to the irregular surface of the ablated cloth.

Polane (Sprayable Polyurethane) - If abrasion is a significant problem in launch tubes, then it follows that a tough elastomer might make a good liner material. A tube was fabricated by applying a sprayable urethane to a mold released mandrel and overwrapping with the baseline tube. The only effect of grit blasting was a dulling of the surface. The torch test darkened the surface to the point of charring. A urethane with higher temperature capability should be considered for future studies.

Epon 828/Nadic Methyl Anhydride/Benzyldimethyl Amine/Cabosil - As an additional experimental control, the baseline Epon 828 resin system with Cabosil was evaluated as a liner material and performed well. The only effect of the torch test was a slight darkening of the resin. The grit test dulled the surface slightly but resulted in no significant ablation.

CTBN Modified Epoxy/Cabosil - Because of its alleged toughness, CTBN modified epoxy was considered as a liner material. The torch test resulted in a darkening of the surface but no significant effect on hardness. The grit test, once again, dulled the surface with no measurable ablation.

Barium-Mica/Epoxy - This tube was not wound by Brunswick but provided by MICOM for evaluation. The Barium-Mica filler was an attempt to make the tube surface less sensitive to rocket exhaust. The liner in the tube provided was very thin (a few thousandths) and did not provide protection from grit ablation. Grit blasting exposed the first fiber layer. The torch test resulted in very little discoloration of the resin, but some light areas indicated the possibility of subsurface delamination. A thicker liner of this type may be worth further consideration.

CONCLUSIONS

Thermal analysis results indicate that at least some rocket launch tubes may be adaptable to an all composite design. The wall temperature associated with high impulse, low burn time rocket systems appears to be low enough (approx. 550°F) to allow the use of an epoxy on the inside diameter, however slower, long burn time systems may require some extra protection in the aft end of the launch tube to survive repeated firings.

From the results of the screening tests, it appears that a liner material is necessary to achieve the goal of reusability. Although the tests performed are qualitative in nature, based on these results, a high temperature matrix material alone does not show much promise of success. In addition, processing and cost disadvantages of most of these high temperature systems make them impractical for high production rate filament winding.

The tests performed for this study did not sufficiently discriminate between liner materials to allow final specific recommendations to be made. However, from test results and intuition, it appears that a relatively good strength retention under exposure to heat combined with abrasion resistance is the prime requirement of a liner material. Of the liner materials investigated, Apco 2447 and Epon 828/NMA with or without fillers (chopped graphite or Barium-Mica) seemed to offer the best potential for further investigation.

The use of fabric materials (i.e., asbestos tape and graphite cloth) in a liner was detrimental to the liner function. It appears that a high resin content layer of several thousandths of an inch in thickness is necessary to provide adequate protection to the tube surface.

Filler material such as graphite and barium-mica may offer advantages but a more discriminating test, such as an actual rocket firing, is necessary to fully evaluate their effect.

RECOMMENDATIONS

Results of this study indicate that reusable composite launch tubes are definitely a possibility. The experimental results point out the difficulty in simulating a rocket exhaust environment in the laboratory. It is recommended that this work be continued, using actual rocket motors as the test vehicle. Emphasis for future work should be placed on liner materials, with increased consideration of manufacturing techniques. In addition, some consideration should be given to the overwrap design. Optimization of the wind pattern is not only important from a strength consideration, but low angle (near longitudinal) fibers on the inside may be more resistant to abrasion from the rocket blast.

Using the results of this study (including MICOM test results) as a starting point, the follow-on program should allow for an iterative selection of materials and designs. If possible, experimental evaluation (rocket motor tests) should be carried out concurrently with material/design selection, so that the selection process can reflect prior results.

For maximum results, it is recommended that this follow-on study consider only material/design systems which use established processing techniques. A parallel, but separate, program could be undertaken which considers a more exotic material requiring a more extensive process development effort, such as polyimides. This would allow the main investigation to proceed undiluted by materials requiring an inordinate amount of time and effort.

More specific recommendations can be made when the results of the tests performed at MICOM are available for review. The MICOM tests and evaluation are somewhat different from those reported here and should provide additional information on the relative merits of the various material systems.

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LIST OF SYMBOLS

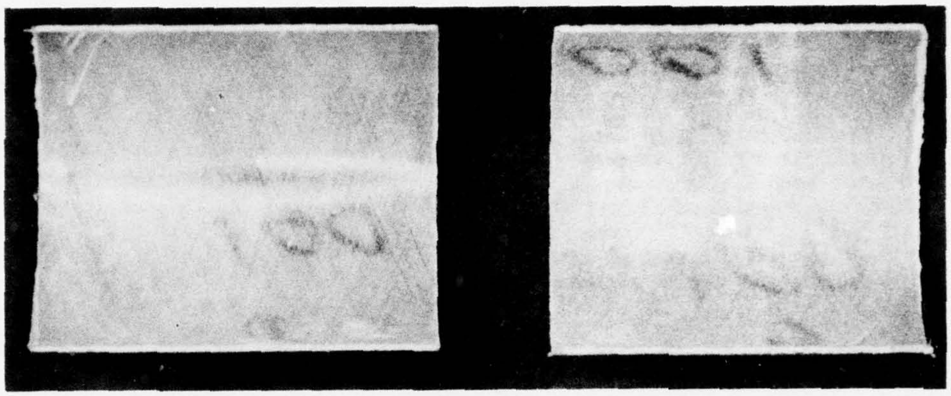
A	Cross Sectional Area of Flow
C_p	Specific Heat
D	Diameter
k	Specific Heat Ratio
M	Mach Number
P	Pressure
Pr	Prandtl Number
R	Gas Constant
h	Convection Heat Transfer Coefficient
V	Gas Velocity
ρ	Density
μ	Viscosity

SUBSCRIPTS

0	Pertaining to the Rocket Chamber
1	Pertaining to the Rocket Throat
2	Pertaining to the Nozzle Exit
3	Pertaining to the Launch Tube

APPENDIX

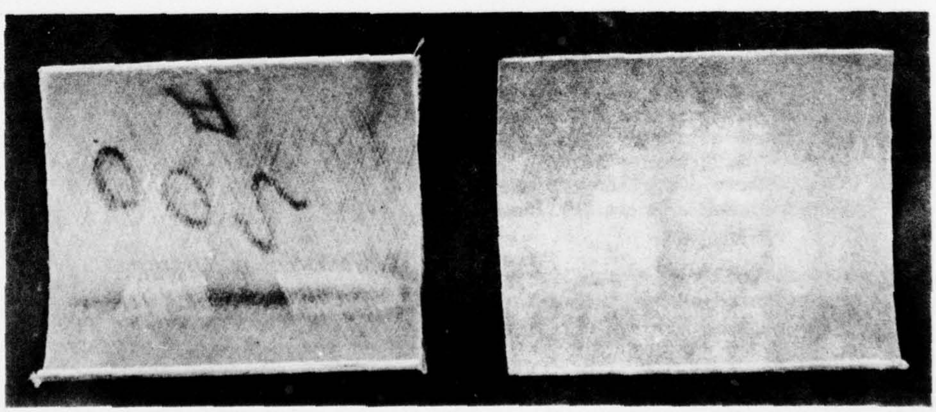
PHOTOGRAPHS OF TESTED SPECIMENS



Torch Test
S/N 001

Matrix: A

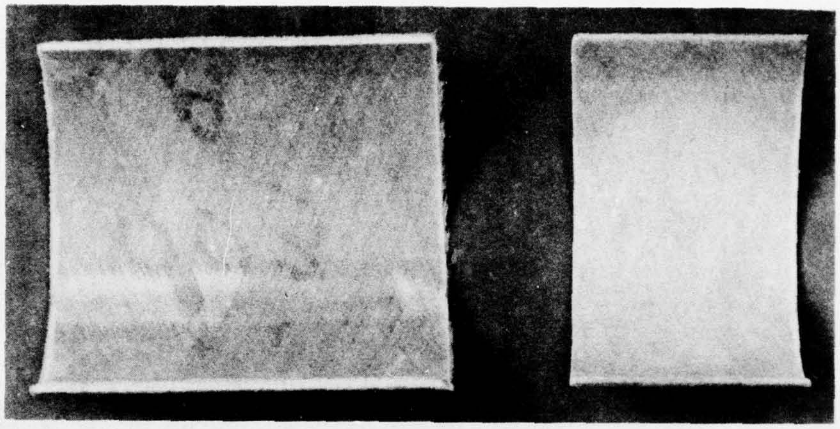
Grit Blast Test
Liner: None



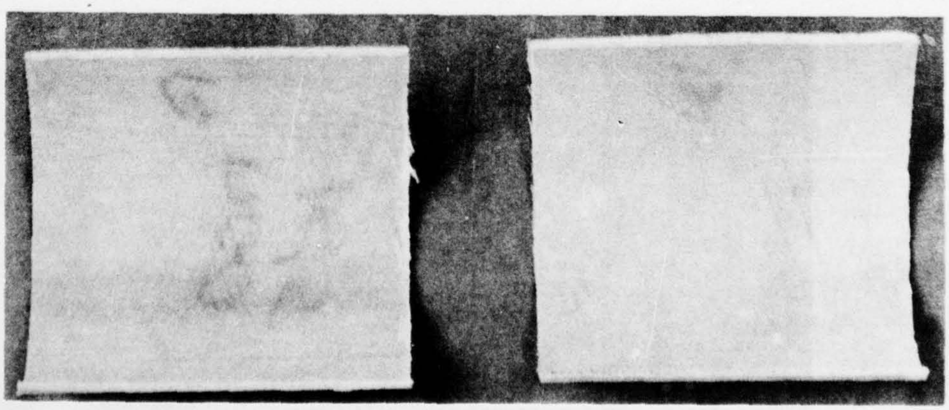
Torch Test
S/N 002

Matrix: B

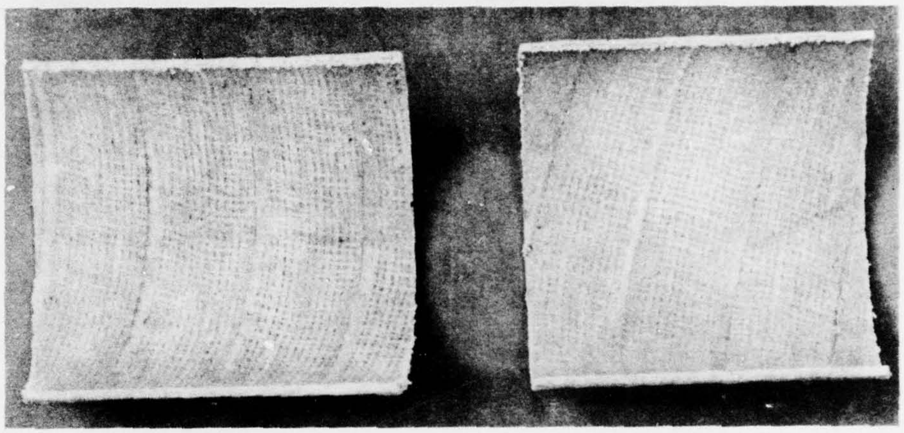
Grit Blast Test
Liner: None



Torch Test S/N 003 Matrix: C Grit Blast Test Liner: None



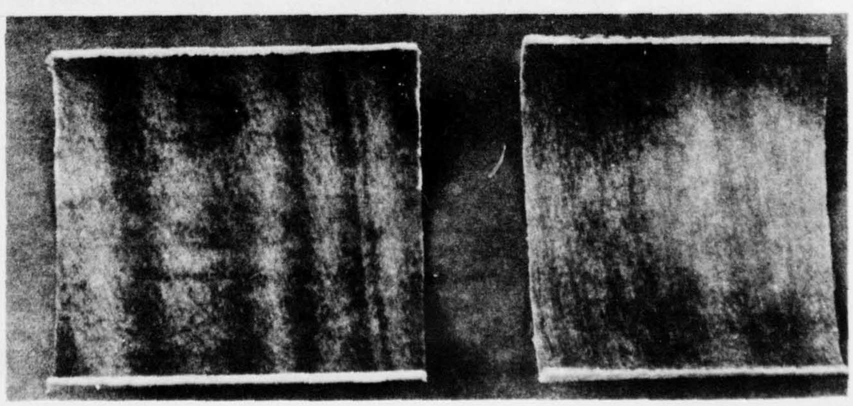
Torch Test S/N 004 Matrix: A Torch/Grit Test Liner: G



Torch Test
S/N 005

Matrix: A

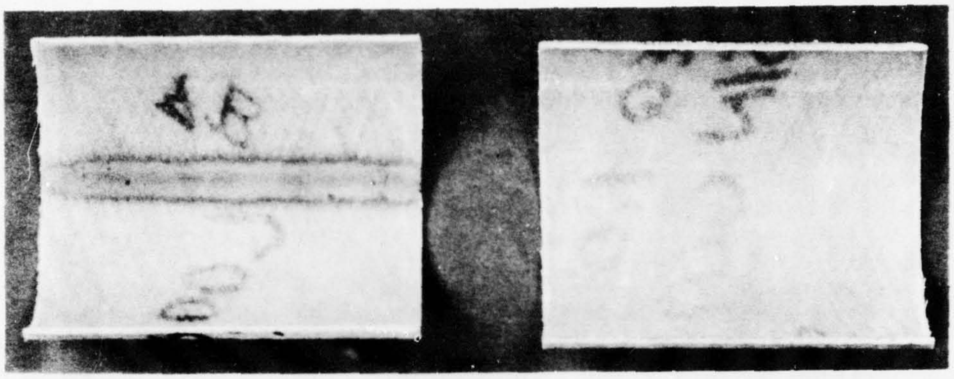
Torch/Grit Test
Liner: H



Torch Test
S/N 006

Matrix: A

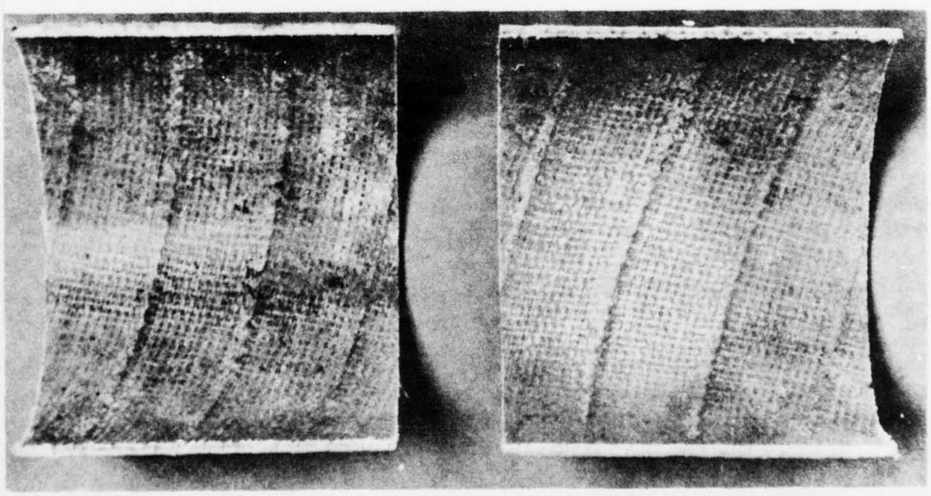
Grit Blast Test
Liner: I



Torch Test
S/N 007

Matrix: A

Grit Blast Test
Liner: J



Torch Test
S/N 008

Matrix: A

Grit Blast Test
Liner: K

AD-A039 067 ARMY MISSILE RESEARCH DEVELOPMENT AND ENGINEERING LAB--ETC F/G 16/1
REUSABILITY OF FILAMENT-WOUND COMPOSITE LAUNCH TUBES WHEN SUBJE--ETC(U)
DEC 76 G A CLODFELTER, D E LOVELACE, W E DICK

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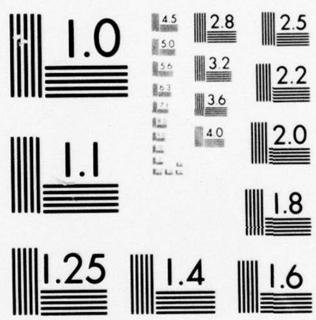
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4.5
5.0
5.6
6.3
2.8
3.2
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2.5
2.2
2.0
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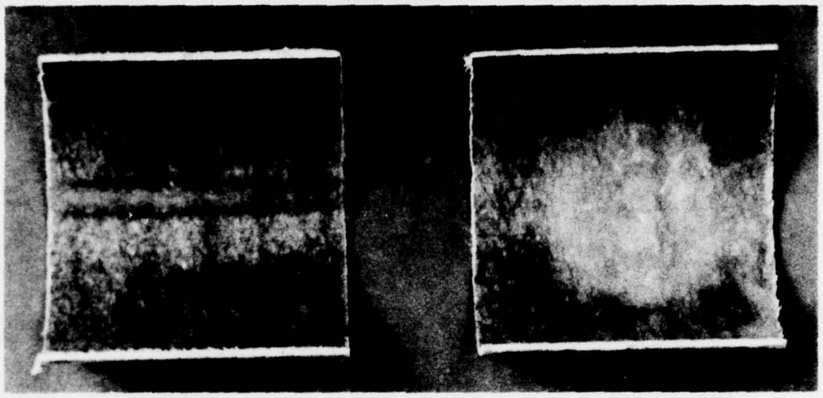
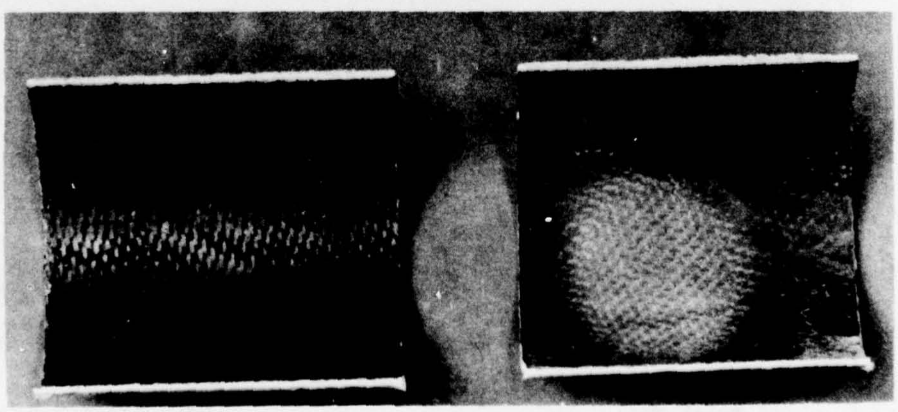
1.25
1.4
1.6



Torch Test
S/N 009

Matrix: A

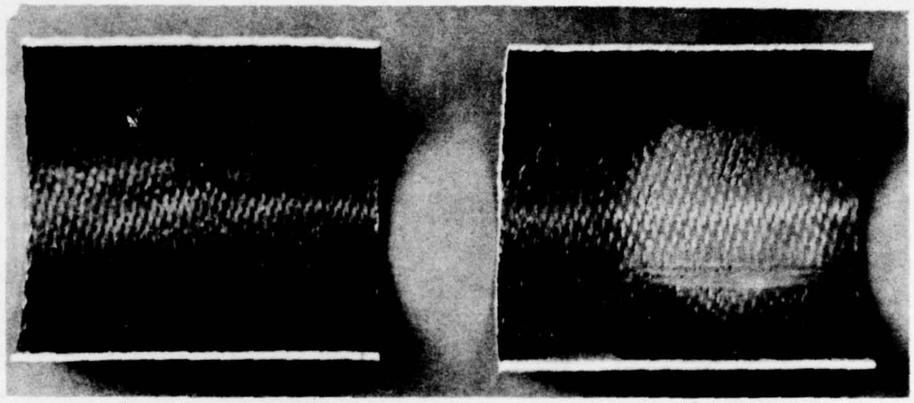
Grit Blast Test
Liner: L



Torch Test
S/N 010

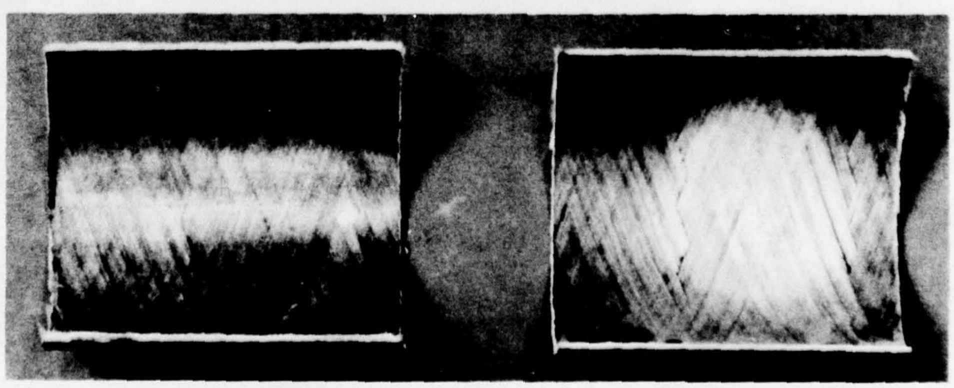
Matrix: A

Grit Blast Test
Liner: M



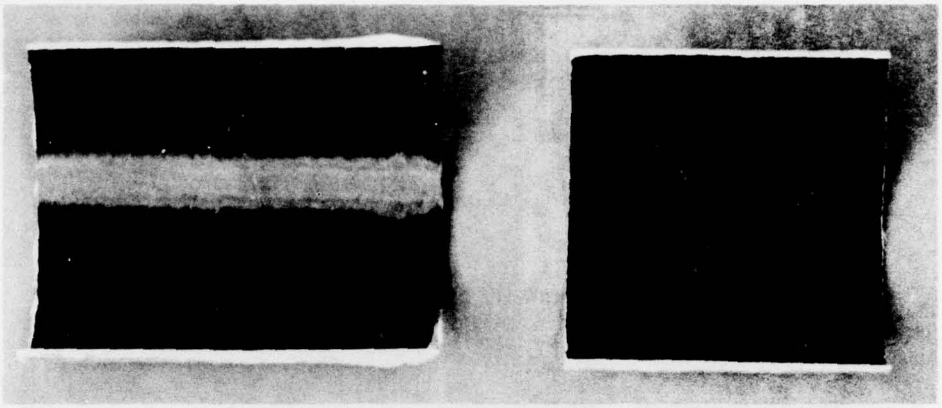
Torch Test
S/N 011 Matrix: A

Grit Blast Test
Liner: N



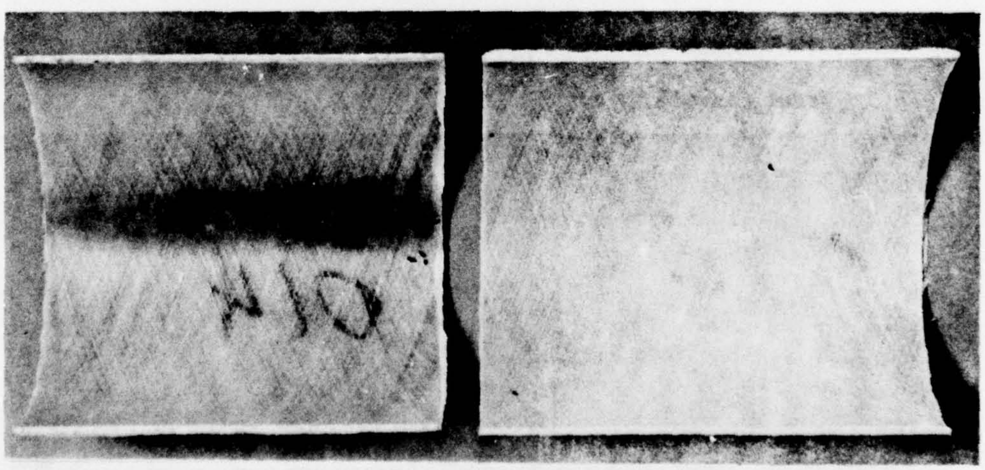
Torch Test
S/N 012 Matrix: D

Grit Blast Test
Liner: None



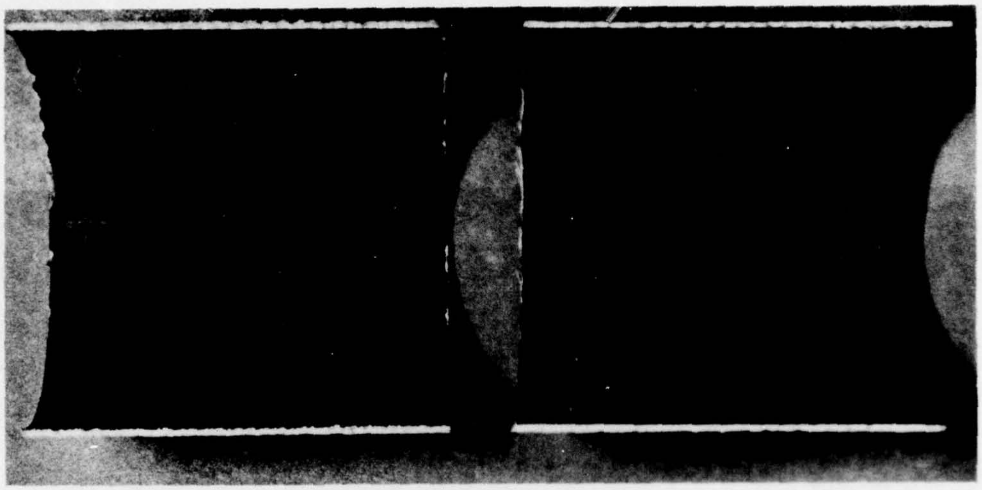
Torch Test
S/N 013 Matrix: A

Grit Blast Test
Liner: O



Torch Test
S/N 014 Matrix: A

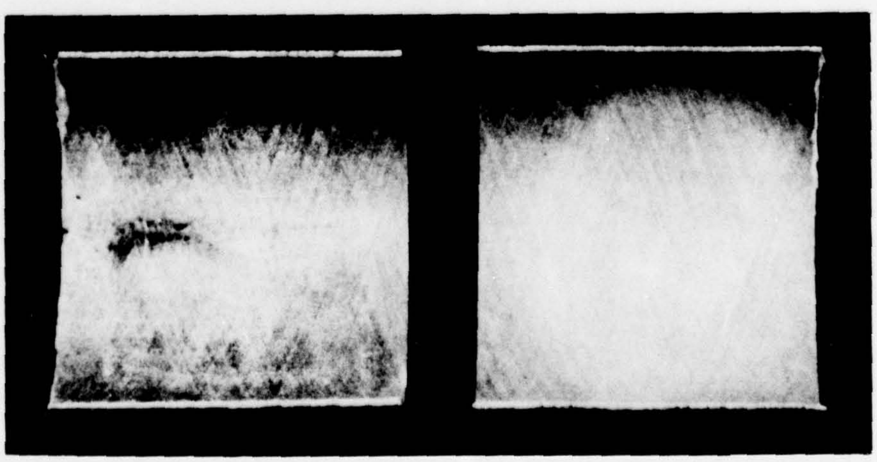
Grit Blast Test
Liner: P



Torch Test
S/N 017

Matrix: A

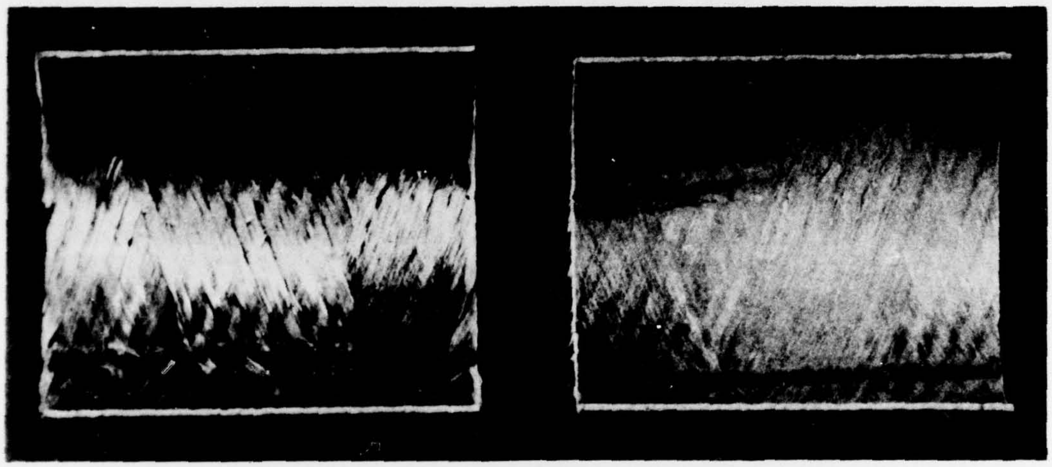
Grit Blast Test
Liner: Q



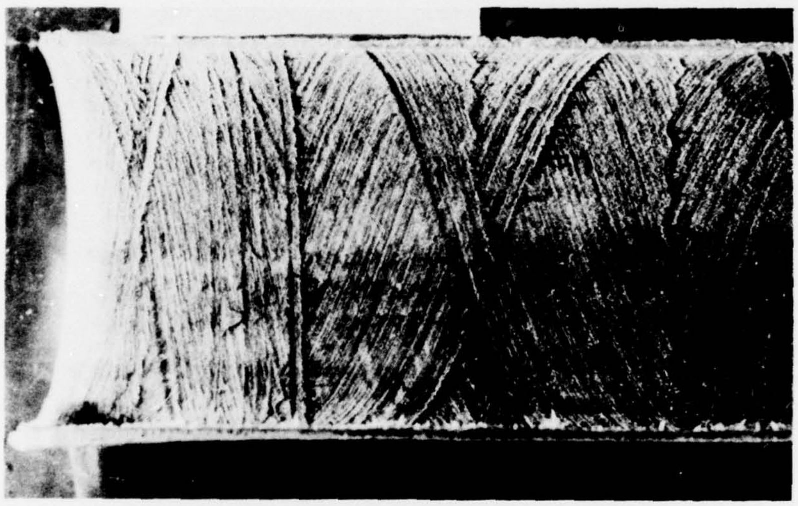
Torch Test
S/N 018

Matrix: E

Grit Blast Test
Liner: R



Torch Test S/N 019	Matrix: F	Grit Blast Test Liner: None



Photograph of a sectioned three inch diameter launch tube which has been subjected to a single firing of a rocket similar to rocket No. 3 in Technical Requirement 6005. The winding matrix is Epon 828/NMA with no liner.

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